CA011073

DOCUMENT REVIEW PANEL PUBLICATION RECORD

A. BIBLIOGRAPHIC DATA

1 PERFORMING AGENCY(IES) Humansystems Incorporated, 111 Farquhar St, 2nd floor, Guelph ON, Canada, N1H 3N4	2 CONTRACT and/or PROJECT NO Contract No. W7711-7-7429/04-SRV
3 SPONSOR (DND Project Officer or Directorate) Director Land Requirements 5-10, National Defence Headquarters, 101 Colonel By Drive, Ottawa ON, Canada, K1A 0K2	4 PUBLICATION SERIES and NO Contract Report 2001-001
5 TITLE (U) Fit Evaluation of Prototype Generation III Fragmentation Vest Designs	
6 PERSONAL AUTHORS Angel, Harold A	7 DATE OF PUBLICATION November 30 , 2000
8 PUBLISHING AGENCY (Name of Establishment) DCIEM	
B. SECURITY CLASSIFICATION / LIMITATION INFORMATION	
9a Overall SECURITY Classification or DESIGNATION of document UNCLASSIFIED	9b DOCUMENT REVIEW DATE January 1 ,
10a. OFFICIAL WARNING TERM (e g Canada/US Eyes Only)	
10b Reasons for Classification or warning term:	

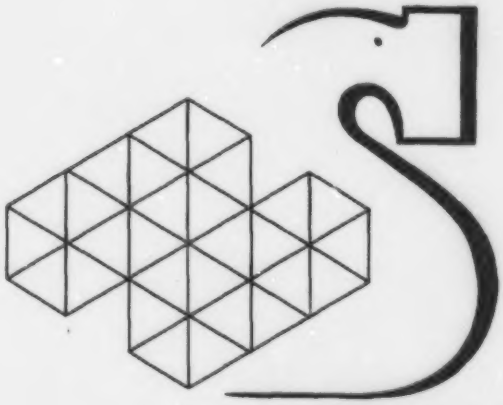
11a. DETAILS OF FOREIGN CLASSIFIED INFORMATION

Country of Origin	Highest Level	PAGES ON WHICH CLASSIFIED OR DESIGNATED INFORMATION IS CONTAINED		
		Text	Tables/Figures	Classified Titles Cited

11b. FOREIGN CLASSIFIED REFERENCES

12 DOCUMENT RELEASABILITY Unlimited distribution	13. APPROVED COUNTRIES

14 DOCUMENT ANNOUNCEMENT
Unlimited
15. REASON FOR NO ANNOUNCEMENT
D AUTHORIZATION
16 Meeting number and date of action of Establishment or HQ Document Review Panel 1-2001 . 21 Feb 2001 DRP Meeting No Date Approved by KM Smith



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Fit Evaluation of Prototype Generation III Fragmentation Vest Designs

PWGSC Contract No. W7711-7-7429/01-SRV
Order No. 7429-04

November 2000

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Fit Evaluation of Prototype Generation III Fragmentation Vest Designs

Location: CFB Petawawa **Trial Date:** 25 May – 28 May 1999

by

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Executive Summary

In 1991, the Canadian Forces (CF) designed and built a fragmentation vest for the protection of our Land Forces personnel against ballistic threats during military operations. Operational deficiencies with the fragmentation vest were reported shortly after introduction into service; these deficiencies included: excessive stiffness, degraded mobility, and incompatibility with helmets, weapon sights and in-service personal load carriage equipment. In order to resolve the in-service vest deficiencies, a series of human factors (HF) investigations were undertaken to develop a new fragmentation vest design. Once a basic design was finalized it was recommended that a detailed fit test should be undertaken to determine tariff and fit boundaries. A hypothetical sizing system containing 11 sizes was developed based on industry standards and the in-service sizing system.

There were three aims to the Generation III Fragmentation Vest Fit Evaluation Trial trial. The first aim of this trial was to conduct a fitting evaluation of modified Generation III Fragmentation Vest sizing system. The second aim was to investigate the degree interference between the hard armour plates and C7A1 rifle firing tasks. The final aim of this trial was to use the results of the trial to propose a sizing and tariff system for the Land Forces.

A three day fit trial was conducted with 198 (168 males and 30 females) subjects at CFB Petawawa during the period 7 to 11 June 1999. Subjects were required to pass through a number of separate fit test stands and anthropometry stands, these stands included: initial fit assignment, dynamic fit acceptance, fit acceptance with ballistic plates, plate interference, ballistic coverage and final fit acceptance. Except for short-small size, the participants achieved an acceptable fit with the 11 vest sizes evaluated for both the plate and no-plate condition.

A requirement for a new extra-small size was identified during the fit trial, the current small chest size fits chest circumferences up to 101.6 cm, which is considered a medium size in industry. All the vest chest sizes could safely accommodate larger chest circumferences than originally hypothesized; suggesting that the existing sizes could be re-labeled to reflect the next size up. Chest circumference provided the highest correlation (R=0.81518) between vest circumferential size selection and body dimension. Suprasternale height provided the highest correlation (R=0.78) between vest length selection and body dimension.. Although ballistic plate and C7A1 rifle clash was witnessed during the fit trial, the effects of plate clash on shooting performance was not evaluated. The fragmentation vest fitting trial identified a number of vest design problem areas, these included excessive vest stiffness (with the camouflage shell), interference at the front of the neck, interference at the arm opening, excessive side overlap and a non-optimal front plate pocket position.

A vest tariff was developed for the Generation III fragmentation vest. This tariff was based on this fitting trial that utilized relatively stiff vest shell materials (camouflage pattern shell). If vests are redesigned, as recommended above, then the vest tariff will have to be re- examined. The calculated vest tariff for the regular component of the Canadian Land Forces is as follows:

Vest Tariff for Regular Force		
Chest Size	Height	Vest Size Tariff[1] Percentage
XSmall	Short	3.4
XSmall	Regular	1.6
XSmall	Tall	0
Small	Short	10.6
Small	Regular	14.9
Small	Tall	3.1
Medium	Short	7.9
Medium	Regular	28.1
Medium	Tall	6.8
Large	Short	3.2
Large	Regular	12.9
Large	Tall	3.9
X Large	Short	0.3
X Large	Regular	2.0
X Large	Tall	0.9
XXLarge	Regular	0.4
Total		100%

Based on the results of this fit trial, further modifications were recommended for the Generation III fragmentation vest. Unforeseen changes to the Generation III vest shell material negatively impacted user acceptance causing subjects to select bigger than anticipated vest sizes.

Résumé

En 1991, les Forces canadiennes (FC) ont conçu et fabriqué un gilet pare-éclats pour la protection du personnel de notre force terrestre contre les menaces balistiques pendant les opérations militaires. Les défaillances opérationnelles de ce gilet ont été signalées peu après son introduction dans le service; on parle ici de rigidité excessive, de mobilité réduite et d'incompatibilité avec les casques, les viseurs et l'équipement personnel de transport de charges du service. Afin de résoudre ces problèmes, une série d'études sur les facteurs humains (FH) ont été entreprises pour développer un nouveau modèle de gilet pare-éclats. Le modèle de base terminé, un essai détaillé d'ajustement a été recommandé dans le but de déterminer les grandeurs requises et les tolérances d'ajustement. Un système de tailles hypothétique à 11 tailles a été élaboré à partir des normes de l'industrie et du système de tailles du service.

L'essai pratique d'ajustement du gilet pare-éclats Generation III avait trois objectifs : évaluer les ajustements du système de tailles du gilet modifié, mesurer le degré d'interférence entre la plaque de blindage dure et les tâches de tir au fusil C7A1 et utiliser les résultats de l'essai en vue de proposer un système de tailles et d'inventaire pour les forces terrestres.

Un essai d'ajustement de trois jours a été mené sur 198 (168 hommes et 30 femmes) sujets à la BFC de Petawawa du 7 au 11 juin 1999. Les sujets ont dû subir plusieurs essais d'ajustement et d'anthropométrie différents, y compris l'essai d'ajustement initial, l'essai dynamique d'acceptation de l'ajustement, l'essai d'acceptation de l'ajustement avec plaque de protection balistique, interférence de plaque, couverture balistique et l'essai d'acceptation final de l'ajustement. À l'exception des petites tailles, les participants ont trouvé un gilet qui leur convenait parmi les 11 tailles de gilet évaluées dans les conditions avec ou sans plaque.

Un besoin d'une nouvelle taille « très petit » a été identifié pendant l'essai d'ajustement. La taille actuelle pour petites poitrines convient à des tours de poitrine d'une circonférence maximale de 101,6 cm, ce qui correspond à une taille moyenne dans l'industrie. Toutes les tailles de poitrine des gilets devraient convenir sans danger aux tours de poitrine plus grands que l'hypothèse d'origine; la suggestion est donc que les tailles existantes soient ré-étiquetées une taille plus grande. Le tour de poitrine a fourni la plus grande corrélation (R=0,81518) entre le choix de la taille de circonférence du gilet et les dimensions du corps. La longueur au-dessus du sternum a donné la plus grande corrélation (R=0,78) entre le choix de la longueur du gilet et les dimensions du corps.

Bien que la plaque de protection balistique et le combat au fusil C7A1 aient été pris en considération pendant l'essai d'ajustement, les effets de combat avec plaque sur la performance de tir n'ont pas été évalués. L'essai d'ajustement du gilet pare-éclats a permis d'identifier des catégories de problèmes de conception, par exemple, la rigidité excessive du gilet (avec le tissu camouflage), l'interférence à l'avant du cou et à l'ouverture pour le bras, un chevauchement des côtés exagéré et un emplacement de la poche avant sur la plaque non optimal.

Un inventaire a été élaboré pour le gilet pare-éclats Generation III à partir de l'essai d'ajustement où des tissus extérieurs de gilet relativement rigides ont été utilisés (à motif camouflage). Si les gilets sont repensés, comme recommandé ci-dessus, alors

l'inventaire devra être revu. L'inventaire calculé du gilet pour l'élément régulier des forces terrestres canadiennes est le suivant :

Inventaire du gilet pour la Force régulière		
Tour de poitrine	Longueur	Pourcentage de l'inventaire
Très petit	Court	3.4
Très petit	Moyen	1.6
Très petit	Long	0
Petit	Court	10,6
Petit	Moyen	14,9
Petit	Long	3,1
Moyen	Court	7,9
Moyen	Moyen	28,1
Moyen	Long	6,8
Grand	Court	3,2
Grand	Moyen	12,9
Grand	Long	3,9
Très grand	Court	0,3
Très grand	Moyen	2,0
Très grand	Long	0,9
Très très grand	Moyen	0,4
Total		100%

D'après les résultats de cet essai d'ajustement, d'autres modifications pourraient être recommandées pour le gilet pare-éclats Generation III. Des changements imprévus de tissu extérieur pour le gilet ont eu un effet négatif sur l'acceptation par les utilisateurs : les sujets ont dû choisir des tailles plus grandes que prévues.

Abstract

In 1991, the Canadian Forces (CF) designed and built a fragmentation vest for the protection of our Land Forces personnel against ballistic threats during military operations. Operational deficiencies with the fragmentation vest were reported shortly after introduction into service; these deficiencies included: excessive stiffness, degraded mobility, and incompatibility with helmets, weapon sights and in-service personal load carriage equipment. In order to resolve the in-service vest deficiencies, a series of human factors (HF) investigations were undertaken to develop a new fragmentation vest design. Once a basic design was finalized it was recommended that a detailed fit test should be undertaken to determine tariff and fit boundaries. A hypothetical sizing system containing 11 sizes was developed based on industry standards and the in-service sizing system.

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Sommaire

En 1991, les Forces canadiennes (FC) ont conçu et fabriqué un gilet pare-éclats pour la protection du personnel de notre force terrestre contre les menaces balistiques pendant les opérations militaires. Les défaillances opérationnelles de ce gilet ont été signalées peu après son introduction dans le service; on parle ici de rigidité excessive, de mobilité réduite et d'incompatibilité avec les casques, les viseurs et l'équipement personnel de transport de charges du service. Afin de résoudre ces problèmes, une série d'études sur les facteurs humains (FH) ont été entreprises pour développer un nouveau modèle de gilet pare-éclats. Le modèle de base terminé, un essai détaillé d'ajustement a été recommandé dans le but de déterminer les grandeurs requises et les tolérances d'ajustement. Un

système de tailles hypothétique à 11 tailles a été élaboré à partir des normes de l'industrie et du système de tailles du service.

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1. Background

The Canadian Forces (CF) have procured and subsequently modified a fragmentation vest for the protection of our Land Forces personnel against ballistic threats during military operations. Operational deficiencies with the fragmentation vest were reported shortly after introduction into service. Deficiencies included: excessive stiffness, degraded mobility, and incompatibility with helmets, weapon sights and in-service personal load carriage equipment. In order to resolve the in-service vest deficiencies, a series of human factors (HF) investigations were undertaken (References B, C, D, E).

Three Canadian body armour manufacturers were approached to produce prototype fragmentation vests in the following configurations: side-opening, front-opening, concealable. All vest designs included the capability for incorporating hard armour ceramic plates onto the front and back of the torso. A HF expert paper-based evaluation of these prototypes was conducted in August 1994 (Reference D). Based on this analysis, the CF down-selected to two vest designs for further feature refinement and subsequent Human Factors (HF) field trial evaluation of the two designs (Reference E).

A detailed one week HF field trial was undertaken in May 1995 to evaluate the two fragmentation vest designs under scientifically controlled testing conditions. This HF trial included assessments of fit and adjustability, performance effectiveness in combat and battle task activities, thermal and physical demands, accessibility, maintainability, User acceptance, and clothing/equipment/vehicle

compatibility, based on the HF criteria developed at Reference C. An additional one-month field evaluation was undertaken by the Land Force Trials and Evaluations Unit (LFTEU) in Gagetown in April 1995 to evaluate the two fragmentation vest designs under appropriate battlefield conditions. The LFTEU trial involved approximately 100 soldiers operating as part of a combat team in all phases of war. Based on the recommendations from these trials, NDHQ selected a concealable, side-opening vest design as most suitable to pursue for the CF Fragmentation Vest Modification Programme.

An additional assessment of the selected fragmentation vest design was subsequently required due to the cancellation of G2122 programme. A decision was made to not salvage the soft armour from existing in-service stocks, but rather to transfer funds and authority to procure a new fragmentation vest as part of the Clothe the Soldier (CTS) Project. The project staff decided to develop two fragmentation vest prototypes incorporating the advantages afforded by new ballistic materials. One design was based upon the latest modification of the earlier Generation II design, and the other upon the "Danish" fragmentation vest design. The primary aim of this field trial was to evaluate the human factors (HF) suitability of two prototype fragmentation vest designs, by comparison with the original Generation II design.

A five-day field trial was undertaken at CFB Petawawa over the period 28 September to 02 October 1998 (Reference F). Three fragmentation vest systems were evaluated by a total of 24 regular force male (n= 16) and female (n=8) participants. A balanced repeated measures comparison between vest conditions was performed. The human factors tests included assessments of fit and adjustability; accessibility; coverage; range of motion; weapon, clothing and equipment compatibility; weapon firing; performance of selected obstacle and combat tasks; battle tasks; comfort; and user acceptance. Data collection included questionnaires, focus groups, performance measures and human factors observer assessments.

The modified Generation II vest (Vest A) was generally rated higher than the Danish version (Vest B) or the original Generation II vest (Vest C) across all evaluation metrics. Vest A was rated the most acceptable vest in the compatibility stands, combat task stands, firing stands, battle task stands and in the exit questionnaire. Vest B was generally rated the least acceptable vest across all evaluation metrics. Vest B was also rated as being unacceptable in many areas. While 74% of the subjects believed that Vest A was the best vest evaluated, 26% of the participants viewed Vest C as the best vest evaluated. None of the participants believed Vest B was acceptable for service issue. Minor modifications to Vest A would make it acceptable by 100% of the participants.

Based on the results of this controlled HF Field trial, Vest A with modifications was recommended for future Canadian Forces (CF) procurement. Modifications and suggestions for further work were suggested. The modifications included:

- relieving the underarm cut by approximately 1.2 cm, and reducing the vest length by approximately 2.5 cm.
- adding a removable collar using snaps and velcro
- changing the shoulder pad design so that the retaining strap is more sturdy
- providing a non slip shoulder and chest butt rest pad
- raising the location of the front hard armour plate pocket
- increasing the length of velcro on front of vest to which the side adjustment straps fasten

An additional outcome of the HF Field Trial was the recommendation for validation of the proposed sizing system of the new vest followed by the development of a tariff for the Land Forces based on the proposed sizing system.

2. Aim

There were three aims to this trial. The first aim of this trial was to conduct a fitting evaluation of modified Generation III Fragmentation Vest sizing system. The second aim was to investigate the degree of interference between the hard armour plates and C7A1 rifle firing tasks and the final aim of this trial was to use the results of the trial to propose a sizing and tariffing system for the Generation III Fragmentation Vest.

3. Method

3.1 Trial Overview

The following description provides a general overview of the trial. Further details are provided in subsequent sections.

A three day fit trial was conducted with up to 198 subjects at CFB Petawawa during the period 7 to 11 June 1999. Subjects were required to pass through up to four fitting (fragmentation vest, rucksack, temperate combat boot, etc.) and anthropometry stands. The fitting, evaluation and anthropometry stands included:

- 2-D Scanning Anthropometry
- Traditional Anthropometry
- Fragmentation Vest Fitting
- Plate Interference

3.2 Trial Conditions

The fit trial involved one style of fragmentation vest. Fit testing was conducted indoors at 1st Battalion the Royal Canadian Regiment.

3.2.1 Fragmentation Vests

The Generation III fragmentation vest used in the fitting trial is a side-opening fragmentation protective vest. The vest was delivered in two outer shell styles, a disruptive camouflage pattern (CADPAT) and an all black pattern – see Figures 1 and 2.

Figure 1: Subject with the Generation III Fragmentation Vest

The fragmentation vest is composed of an outer protective shell and an inner ballistic fill assembly. The ballistic fill panels are enclosed in water proof rip stop nylon bags. The vest is composed of the following components:

- Front shell panel
- Front ballistic fill panel
- Back shell panel
- Back ballistic fill panel
- Detachable shoulder pads
- Detachable neck guard

Please see Annex A for a complete description of the trial vest. The fragmentation vests were produced in 12 different sizes according to Table 1 below.

Chest Size	Height	Chest Measurement (Inches)	Front Panel Length (Inches)
Small	Short	36-38	15.5
Small	Regular	36-38	16.5
Small	Tall	36-38	17.5
Medium	Short	40-42	16.5
Medium	Regular	40-42	17.5
Medium	Tall	40-42	18.5
Large	Short	44-46	17.5
Large	Regular	44-46	18.5
Large	Tall	44-46	19.5
X Large	Short	48-50	18.5
X Large	Regular	48-50	19.5
X Large	Tall	48-50	20.5

3.2.2 Participants

Participants were recruited from units at CFB Petawawa. These units included:

- 2 Field Ambulance (5 pers)
- 2 Service Battalion (15 pers)
- 2nd Combat Engineer Regiment (30 pers)
- 2 CMBG Headquarters and Signals Regiment (10 pers)
- The Royal Canadian Dragoons (20 pers)
- 2 Royal Canadian Horse Artillery Regiment (20 pers)
- 1st Battalion the Royal Canadian Regiment (50 pers)
- 3rd Battalion the Royal Canadian Regiment (50 pers)

Although a total of 198 personnel participated in the fit test, seven of these subjects did not complete all test stands due to conflicting commitments (medical appointments, career training, etc.). If a subject participated in a test stand their results were included for statistical analysis. Personnel included 30 females and 168 males. While the majority of participants were regular force, a small number were militia personnel on call-outs.

3.3 Data Collection

Data collection included physical measures, questionnaires, subject comments, HF observation and interviews and subjective assessments – see Figure 2.

Figure 2: Subject Completing an Exit Questionnaire.

Participants rated acceptability in all stands and questionnaires using the following seven-point scale (Figure 3).

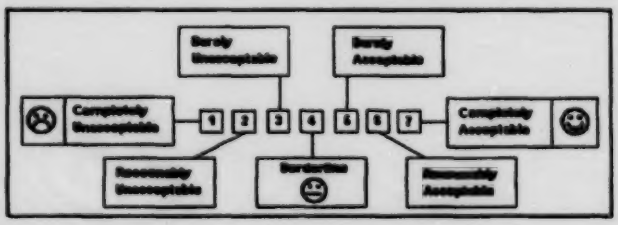


Figure 3: Standard Rating Scale

The fitting, evaluation and anthropometry stands included:

- 2-D Scanning Anthropometry
- Traditional Anthropometry
- Fragmentation Vest Fitting
- Plate Interference

3.3.1 2-D Scanning Anthropometry Test Stand

Selected participants were measured using DCIEM's 2-D Intelligent Clothing and Equipment Sizing System (ICESS). DCIEM personnel ran this stand. This automated scanning system run by DCIEM derived the following anthropometric measures:

- Stature
- Neck circumference
- Chest circumference
- Waist circumference
- Hip circumference
- Sleeve length
- Back length
- Neck base height
- Neck to waist vertical height
- Strap length

Additionally, the ICESS predicted the garment sizes for rucksacks which will be reported separately.

3.3.2 Traditional Anthropometry Test Stand

In addition to the 2-D anthropometry ICESS stand, subjects were measured by DCIEM manually for:

- Suprasternale height
- Iliocristale height
- Waist (omphalion) circumference

3.3.3 Fragmentation Vest Fitting Test Stand

After completing the ICESS and traditional anthropometric stand, the subjects commenced the actual fit testing. Fit testing included the following stands:

- Initial assessment
- Dynamic Fitting assessment
- Coverage assessment
- Exit Questionnaire

3.3.3.1 Initial Assessment:

Based upon their anthropometric measures, subjects were mapped (based on torso length vs chest circumference) against a hypothetical fragmentation vest sizing system. This sizing system was overlaid against the DCIEM 97 Land Forces Anthropometric Survey (Reference G). The aim of this initial assessment was to focus fitting efforts on different sizes of torsos that represent the breadth of the Land Forces population. Based on their anthropometric measurements, subjects were assigned an initial fragmentation vest size based on the hypothetical vest sizing system – see Figure 4.

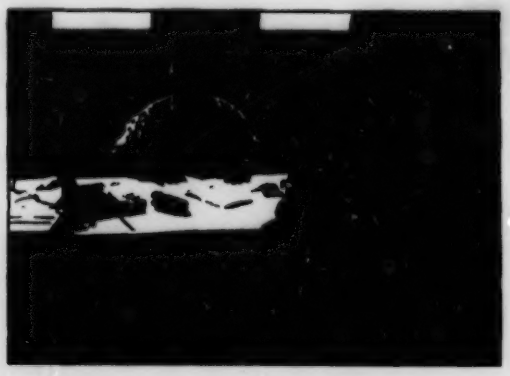


Figure 4: Initial Vest Assignment Based on ICESS data.

The hypothetical sizing system was based on the Generation II sizing system and other commercial and military sizing systems. The hypothetical sizing system is detailed below in Table 1.

Chest Size	Torso Length	Size Abbr.	Chest Circumference (mm)	Stature (mm)
Small	Short	SS	914.4 – 965.2	<1676.4
Small	Regular	RS	914.4 – 965.2	1676.4 – 1854.2
Small	Tall	TS	914.4 – 965.2	>1854.2
Medium	Short	SM	101.2 – 1066.8	<1676.4
Medium	Regular	RM	101.2 – 1066.8	1676.4 – 1854.2
Medium	Tall	TM	101.2 – 1066.8	>1854.2
Large	Short	SL	1117.6 – 1168.4	<1676.4
Large	Regular	RL	1117.6 – 1168.4	1676.4 – 1854.2
Large	Tall	TL	1117.6 – 1168.4	>1854.2
XLarge	Short	SXL	1219.2 – 1270	<1676.4
XLarge	Regular	RXL	1219.2 – 1270	1676.4 – 1854.2
XLarge	Tall	TXL	1219.2 – 1270	>1854.2

Table 1: Hypothetical Sizing System

Once appropriately sized, the subjects were briefed on the various fit and adjustment features of the fragmentation vest. Subjects were then asked to move around bending and twisting in order for them to assess the initial fit of the vest.

One investigator observed the movements and questioned the subject on a number of fit and comfort related factors – see Annex B. If the initial fit was too short/long or tight/loose, the adjacent size in the indicated direction was tried if possible (note this was not possible for subjects who found the small vests too large and for one individual who found the extra-large vest too small. Once the subject found the "best " fitting vest they proceeded to the dynamic fit assessment task stand.

3.3.3.2 Dynamic Fitting Assessment:

Subjects were asked to perform a number of dynamic movements to discover if there were any task-related fitting or comfort problems. Dynamic tasks included:

- waist bending, torso twisting
- arm and shoulder rotation
- neck rotation
- simulated driving task
- standing rifle firing
- prone rifle firing

One investigator observed the movements and questioned the subject on a number of fit and comfort related factors – see Figure 5 as well as AnnexC. Photographs were taken of problem areas- see Figure 6.

Figure 5: Subjects Performing Dynamic Fit Tests with the C7A1 Rifle.

Figure 6: Photographed Vest Design Problem (Underarm Area).

3.3.3.3 Protective Coverage Assessment:

With the vest adjusted and properly fitted to the participants, the limits of soft armour coverage were measured in the standing posture –see Figure 7. The standing coverage measures included:

- height of the soft armour hem(front and back) relative to the iliocristale height,
- height of the front of the neck opening relative to the sternal notch
- coverage across the top of the shoulders
- gap breadth or overlap at sides

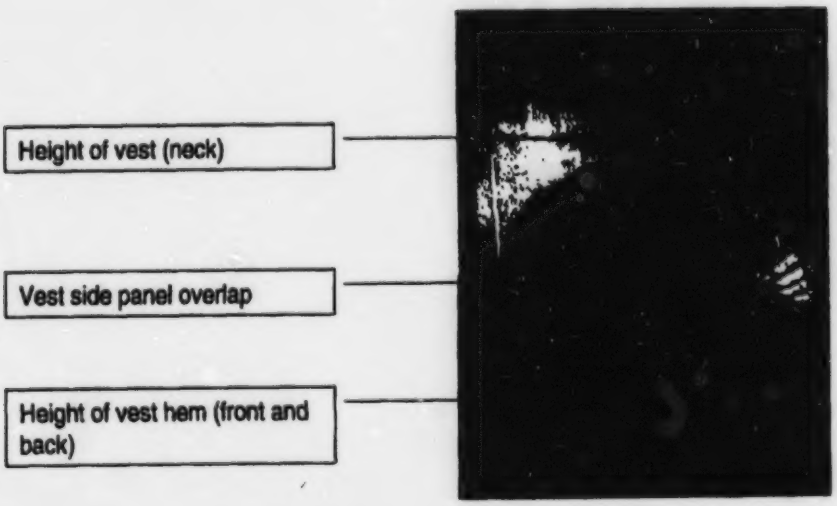


Figure 7: Protective Coverage Assessment.

3.3.3.4 Plate Interference Test Stand

Upon completion of the fragmentation vest fitting stands, each subject participated in a plate interference test. Subjects were briefed on plate installation procedures and instructed on how to determine the proper plate height. Subjects then installed the front and back plates into the vest. Subjects were then assessed on their first impression of vest fit with plates – see Annex D. Subjects then were asked to rate the acceptability of fit as well as several other comfort-related questions.

Subjects were then required to adopt the standing and kneeling C7A1 unsupported rifle firing position. One investigator observed the movements and questioned the subject on a number of fit and comfort related factors – see Figure 8.

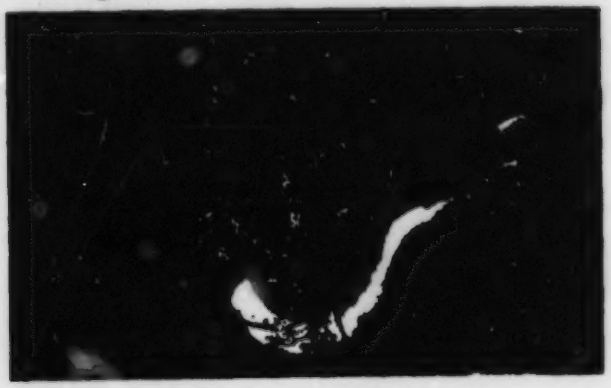


Figure 8: Subject Assessing Plates in the Prone Unsupported Position.

While adopting the correct shooting position subjects were questioned to determine the presence of plate clash. If clash is present, the location of the rifle butt was traced on the vest with chalk. The amount of clash with the rifle butt and plate was subsequently traced with a clear acetate and then transferred manually to paper.

3.3.4 Exit Fit Questionnaire:

Upon completion of adjustment, fitting and assessment of coverage, participants completed an Exit Fit Questionnaire – see Annex E.

3.3.5 Limits of the Sizing System

Using the results of the fitting trial, acceptable vest size assignment and body dimensions were utilized to determine the limits of the sizing system. Both qualitative and quantitative data were used to determine the best fitting size for chest circumference and torso length.

3.3.6 Land Forces Tariff:

Once the limits of the sizing system were determined, the Land Forces Survey (Reference G) and demographic profile of the Land Forces (Reference I) was used to develop a Land Forces tariff. The Land Forces Survey database was sorted into predicted sizes and the relative frequency of males and females were used to set the tariff.

3.4 Trial schedule

Table 2 outlines the three-day fit trial schedule.

Timings	Monday 7 June 99	Tuesday 8 June 99	Wednesday 9 June 99
0700 - 0800	Set-up	HQ and Sigs (10 pers)	3 RCR (50 pers)
0800 – 0900		RCD (20 pers)	
0900 – 1000			
1000 –1100	2 Fd Amb (5 pers)	2 RCHA (20 pers)	
1100 – 1200	2 Svc Bn (15 pers)		
1200 – 1300	2 Svc Bn/Lunch	2RCHA/Lunch	Lunch
1300 – 1400	2 CER (30 pers)	1 RCR (30 pers)	1 RCR (36 pers)
1400 – 1500			
1500 - 1600			
1600 - 1700			Tear-down

Table 2: Trial Schedule

4. Results

Trial results are summarized below for the following section:.

- Participant profile
- Initial assessment
- Dynamic assessment
- Plate interference assessment
- Coverage assessment
- Overall fit assessment
- Sizing system limits
- Land Forces tariff

4.1 Participant Profile

A total of 198 subjects participated in the fit trial. These participants included 168 males and 30 females. The trial participants included the following:

	Combat Arms	Non-Combat Arms	Total
Males ♂	72.2% (143)	12.6% (25)	84.8% (168)
Females ♀	0% (0)	15.1% (30)	15.1% (30)
Total	72.2% (143)	27.8% (55)	100% (198)

4.2 Anthropometry Results

All the participants were measured using DCIEM's 2-D Intelligent Clothing and Equipment Sizing System (ICESS). A total of 168 males and 30 females were measured.

The trial participants anthropometric measurements were compared to the 1997 DCIEM Land Forces Anthropometric Survey (see Tables 3 and 4 as well as Figure 9 below) to determine whether the trial participants were different than the personnel measured in the 1997 DCIEM Land Forces Anthropometric Survey. A Student's T-test for independent samples was undertaken for each anthropometric measurement by gender. Mean and standard deviations are provided.

Except for just two measures – chest circumference and buttock circumference, the male fit trial subjects were significantly different ($p < 0.05$) than the males measures in the 1997 DCIEM Land

Forces Anthropometric Survey. The fit trial males were significantly taller and had smaller waist sizes.

	Land Forces Survey Males (n=466)		Fragmentation Fit Trial Males (n=162)	
	Mean	Std Dev	Mean	Std Dev
Stature (mm)	1755	66	1767	69
Acromial Ht (mm)	1434	60	1478	78
Suprasternale Ht (mm)	1428	58	1441	58
Iliocristale Ht (mm)	1060	50	1136	73
Chest circumference (mm)	1027	82	1016	82
Waist circumference (NI) (mm)	900	100	863	152
Waist circumference (Omph) (mm)	924	104	894	104
Waist-back length (mm)	414	25	509	355
Buttock circumference (mm)	1009	68	1012	64

Significant differences ($p<0.05$)

Table 3: Comparison between the LF 97 Survey Males and MOAFT Subjects

Except for heights and chest circumference, the female fit trial subjects were significantly different ($p< 0.05$) than the females measured in the 1997 DCIEM Land Forces Anthropometric Survey. The fit trial females were had significantly smaller waist and buttock sizes.

	Land Forces Survey Females (n=243)		Fragmentation Fit Trial Females (n= 30)	
	Mean	Std Dev	Mean	Std Dev
Stature (mm)	1636	57	1635	58
Acromial Ht (mm)	1342	55	1358	60
Suprasternale Ht (mm)	1332	51	1327	51
Iliocristale Ht (mm)	995	44	993	201
Chest circumference (mm)	953	94	919	101
Waist circumference (NI) (mm)	780	105	750	75
Waist circumference (Omph) (mm)	885	129	802	80
Buttock circumference (mm)	1025	87	978	88

Significant differences ($p<0.05$)

Table 4: Comparison between the LF 97 Survey Females and MOAFT Subjects

Measurement error and unique sub-populations may explain the difference between the MOAFT and LF 97 Survey males. Despite standardized protocols, the accuracy or repeatability in obtaining anthropometric measurements is low. Misidentification of land marks, faulty posture, faulty technique, incorrect instrument use, parallax, etc. all create repeatability problems. The LF 97 Anthropometric Survey team had significantly more training and practice than the MOAFT anthropometric measuring team.

While ICESS eliminates a number of manual anthropometry measurement sources of error, it introduces newer sources. These include errors inherent in the circumference algorithm models, variability in cranium hair thickness, camera calibration, etc. During initial vest assignment a number of errors were discovered with the ICESS assigned body measurements. One subject was assigned a chest circumference of 798mm by ICESS but was discovered to have a chest circumference of 1118 mm when measured traditionally.

MOAFT subjects may be physically different than the population measured in the 97 Land Forces Survey. A total of 72.2% of the MOAFT male subjects were combat arms soldiers and officers versus the 97 Land Forces Survey where 36.9% of the subjects were combat arms personnel. The combat arms soldiers are also generally younger (average age of the combat arms personnel in the 97 Land Forces Survey was 28.8 versus 32.7 for the non-combat arms personnel). As a population ages it generally increases in mass until about age 50 to 60 where it begins to shrink. As well, stature begins to shrink at about 40 years of age. The age of the MOAFT participants was not elicited.

Not withstanding the general fitness requirements of the Land Forces, combat arms personnel are generally fitter than non-combat arms personnel (the combat arms personnel of the 97 Survey had a mean body fat content of 13.1% versus over 17% for non-combat arms personnel). Thus, the 97 Land Forces Survey personnel (males and females) could be expected to have greater waist girth measures than the MOAFT personnel (observed).

A somewhat representative sample of female subjects was captured in the fitting trial. A scatterplot of chest circumferences and statures of female MOAFT participants (•) versus females in the 97 Land Forces Survey (O) is displayed below in Figure 9.

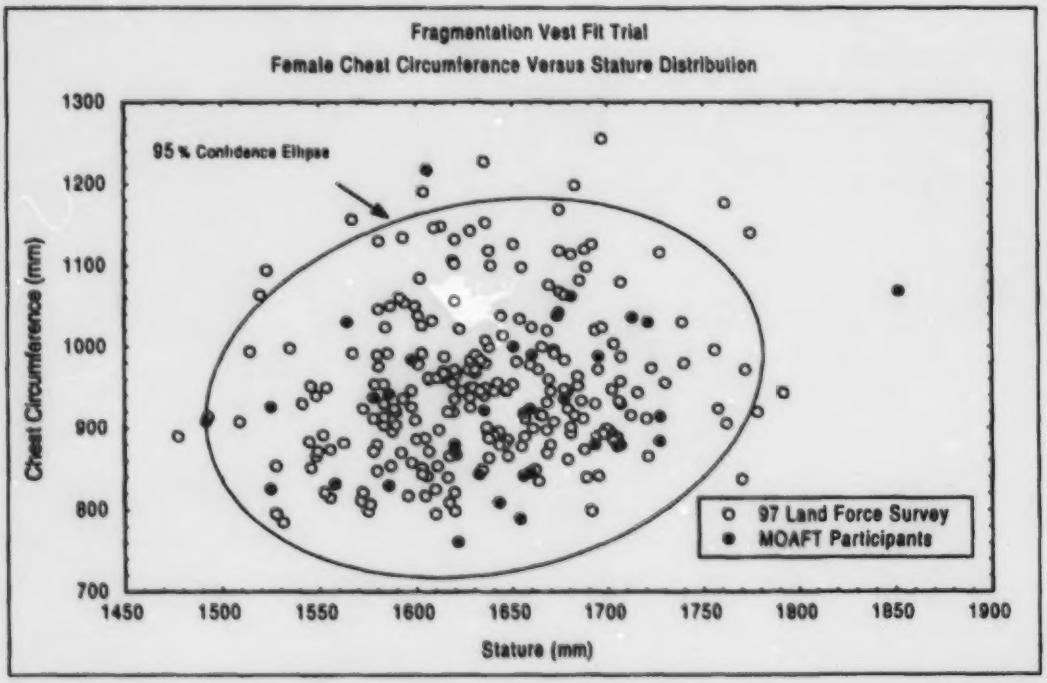


Figure 9: Bivariate plot of MOAFT Female Participants and 97 Land Forces Survey Female Participants for Chest Circumference and Stature.

A somewhat representative sample of male subjects was captured in the fitting trial. A scatterplot of chest circumferences and statures of male MOAFT participants (•) versus males in the 97 Land Forces Survey (O) is displayed below in Figure 10

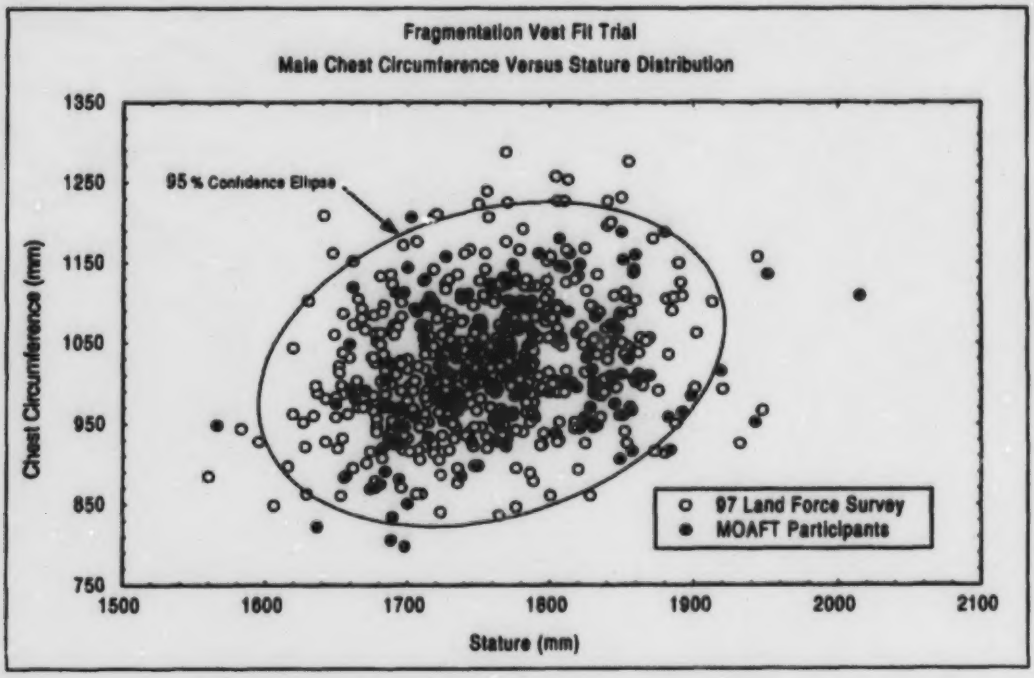


Figure 9: Bivariate plot of MOAFT Male Participants and 97 Land Forces Survey Male Participants for Chest Circumference and Stature.

4.3 Initial Vest Assignment

After the participants were measured using DCIEM's 2-D Intelligent Clothing and Equipment Sizing System (ICESS) they were assigned a vest according to the hypothetical sizing system (see Table 1). Once appropriately sized, the subjects were briefed on the various fit and adjustment features of the fragmentation vest and were then asked to move around bending and twisting in order for them to assess the initial fit of the vest.

After their initial assessment, a total of 24 subjects were reassigned to another vest size – see Figure 10.

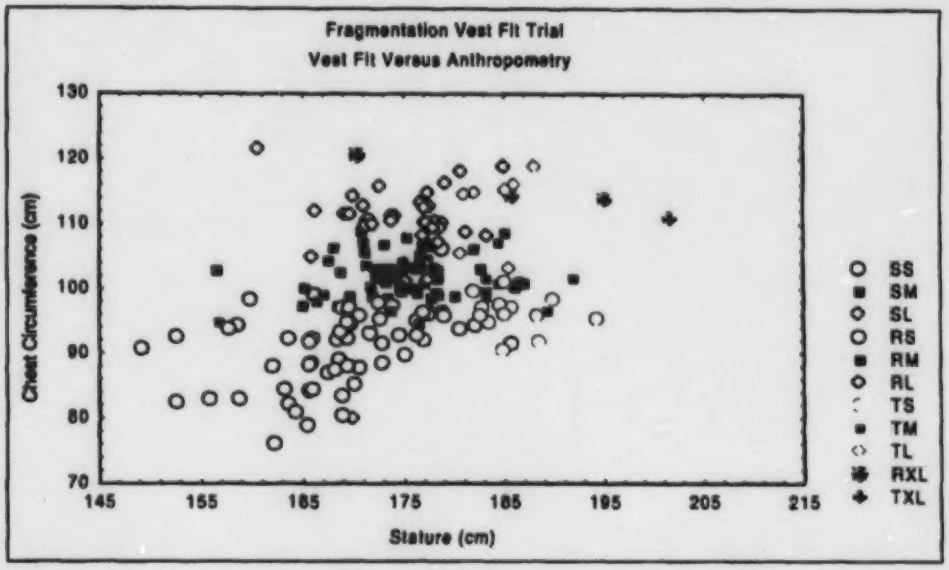


Figure 10: Vest Assignment versus Anthropometry

A total of 14 subjects were reassigned a different torso length and 9 subjects were reassigned a different chest circumference. One subject was assigned a vest with a different chest size and torso length. After this initial test the trial subjects were assigned to the following vest sizes- see Table 5 (note only subjects who completed all fit test stands are included).

Vest Size	Total (n)
SS	31
SM	9
SL	8
RS	28
RM	51
RL	29
TS	14
TM	10
TL	7
RXL	1
TXL	3
Total	191

Table 5: Vest Assignment.

During the initial fit session, subjects were first test fitted according to the hypothetical fitting scheme and then for comparison they were test fitted with adjacent sized vest(s). Thus if a subject was wearing a medium sized vest, they were also tested with a small or large sized vest as appropriate. Nearly all the subjects chose the initially assigned vest as the "best" fitting vest. While the vests appeared to be large for most of these subjects, only a very few wanted a tighter fitting vest. Subjects commented that the tighter fitting vests had more neck pressure points "choking"and arm opening discomfort. Once the subject selected the "best" fitting vest they were questioned on a number of fit and comfort related factors – see Appendix 2.

4.4 Initial Fit Acceptance

After matching the subjects to the "best" fit achievable, the subjects were questioned on their perceptions of their initial fit. Three female subjects could not achieve an acceptable fit with the vest sizes available. These three subjects found that the Short Small (SS) was still too large to get an acceptable fit. Overall, the subjects rated themselves as achieving a "Reasonably Acceptable" initial fit- see Figure 11 and Table 6.

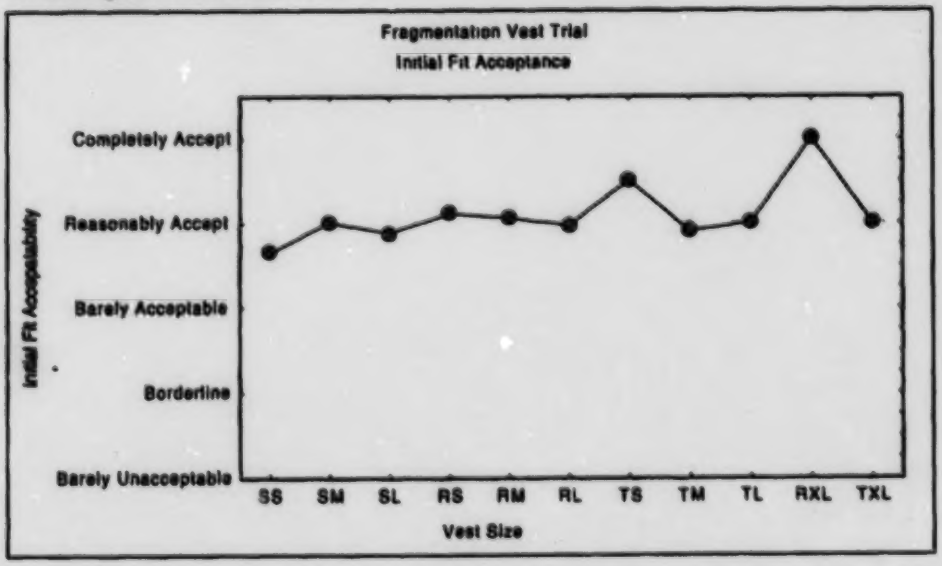


Figure 11: Initial Fit Acceptance Rating (Mean)

A total of 98.5% of the subjects rated the fit as being acceptable. Of the subjects who rated the vest fit as acceptable, 88.5% rated the vest fit as optimal, 7% rated the vest as being slightly small and 3% rated the vest as being slightly large.

Vest Size	Mean	SD	Total (n)
SS	5.6	1.3	31
SM	6.0	0.9	9
SL	5.9	1.0	8
RS	6.0	0.9	29
RM	6.0	0.7	55
RL	6.0	0.8	29
TS	6.5	0.6	14
TM	5.9	0.5	11
TL	6.0	0.6	7
RXL	7.0	0.0	1
TXL	6.0	1.0	3
Total	6.0	0.9	197

Table 6: Initial Fit Acceptance Rating

4.4.1 Pressure Points

A total of 37 subjects (18.7%) reported pressure point discomfort when wearing the vest. Discomfort was isolated to the areas of the underarm (n=12) – see Figure 6, neck region (n=6)- see Figure 12, hip and belt region (n=12)- see Figure 13 and to the ribs and side (n=7). There was no correlation between reported pressure point discomfort versus fragmentation vest size. Subjects reported that the CADPAT covered vest was extremely stiff and thus caused pressure point problems.

Figure 12: Site of Neck Discomfort

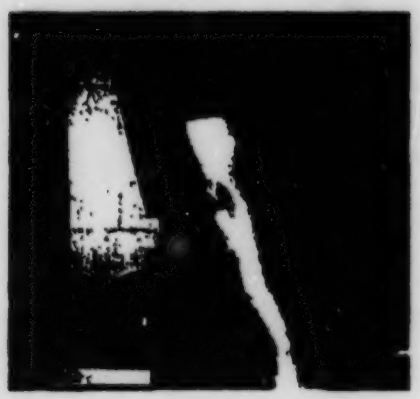


Figure 13: Site of Hip and Back Discomfort

4.4.2 Chaffing

A total of 70 subjects (35.5%) reported chaffing discomfort when wearing the vest. Discomfort was isolated to the areas of the underarm (n=37), neck region (n=29), hip and belt region (n=4) and to the ribs and side (n=3). There was no correlation between reported chaffing discomfort versus fragmentation vest size. As for pressure points, subjects reported that the CADPAT covered vest was extremely stiff and chaffed during movement.

4.4.3 Overall Comfort

Overall the subjects rated the comfort of the vests as being "Reasonably Acceptable" – see Figure 14 and Table 7. There was no correlation between comfort versus fragmentation vest size. All of the subjects reported that the generation III fragmentation vest design was a great improvement on the in-service fragmentation vests (Generation 0 and 1).

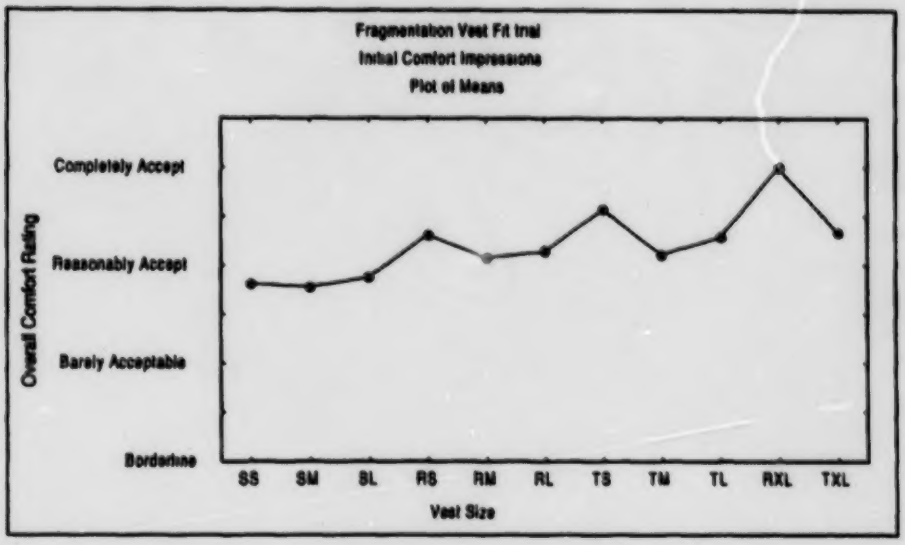


Figure 14: Overall Initial Impression - Comfort Rating

As for pressure points, subjects reported that the CADPAT covered vest was extremely stiff and chaffed during movement.

Vest Size	Mean	SD	Total (n)
SS	5.8	1.4	31
SM	5.8	1.9	9
SL	5.9	0.8	8
RS	6.3	0.7	29
RM	6.1	0.7	55
RL	6.1	0.7	29
TS	6.6	0.5	14
TM	6.1	0.3	9
TL	6.3	0.5	7
RXL	7.0	0.0	1
TXL	6.3	0.6	3
Total	6.0	0.9	195

Table 7: Initial Impression - Overall Comfort Rating

4.5 Dynamic Fit Acceptance

After their initial fit assessment, subjects were asked to perform a number of dynamic movements to discover if there were any task-related fitting or comfort problems. Overall, the subjects rated the dynamic fit acceptance of the vests as being 'Reasonably Acceptable" – see Figure 15. There was no correlation between overall acceptance versus fragmentation vest size.

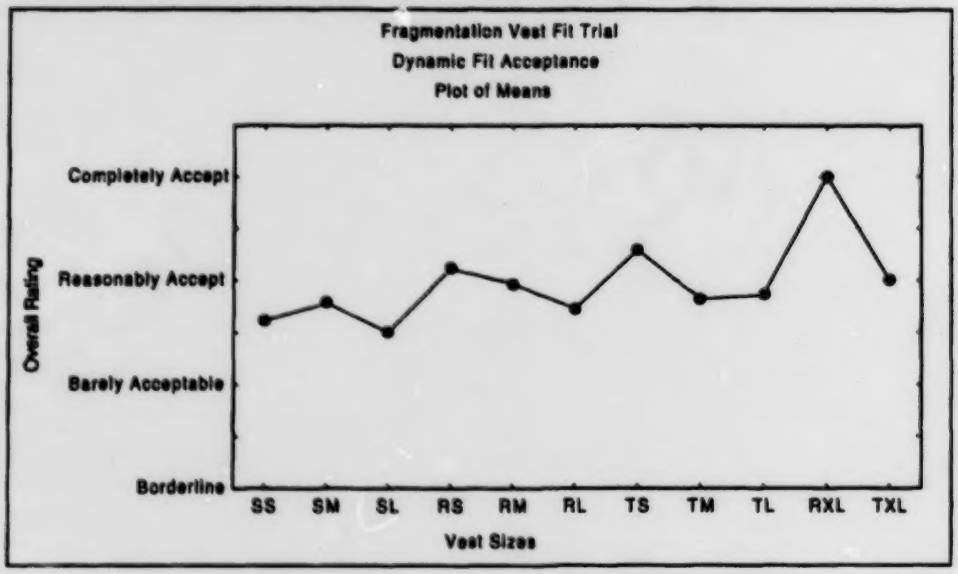


Figure 15: Dynamic Fit Acceptance - Overall Acceptance Rating

4.5.1 Waist Bending, Twisting

Only one subject reported unacceptable waist bending performance. This subject was wearing a vest that was too large for her (SS). Subjects reported that they could flex more easily in the new vest as compared to the in-service vests. Overall the subjects rated waist bending and twisting with the new vest as being "Reasonably Acceptable".

4.5.2 Arm Movement

Although only a total of 11 subjects reported unacceptable arm movement performance, a total of 81 subjects commented on problems with arm movement. Thirty-six subjects reported that arm movement caused choking problems at the neck and a further 45 subjects commented that the vest design restricted some arm movement – see Figure 16. Raising the arms above the head was particularly problematic. Overall the subjects rated arm movement with the vest as being '"Reasonably Acceptable". There was no correlation between those that rated the vest as unacceptable for arm movement and vest size.

Figure 16: Restrictive Arm Opening

4.5.3 Neck Movement

Two subjects rated neck movement with the vest as being unacceptable and although a further 13 subjects reported problems with neck movement, they still rated neck movement as acceptable. These subjects commented that the neck fit was too tight causing chaffing – see Figure 17. Overall the subjects rated neck movement with the vest as being "'Reasonably Acceptable". It should be noted that neck movement was accomplished without a helmet.

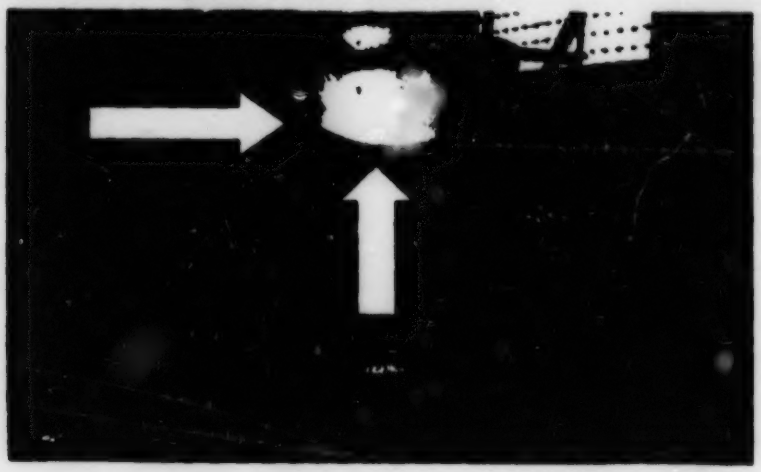


Figure 17: Areas of Neck Chaffing

4.5.4 Simulated Iltis driving

Although a large number of subjects (47) commented on problems during the simulated driving task only seven subjects rated the compatibility of the vest with simulated Iltis driving as being unacceptable. Twenty-two subjects reported neck discomfort with the simulated driving task and further 18 subjects commented that they experienced problems at the arm opening. Finally seven subjects commented that the vest cut into their thighs during the simulated driving task. Overall the subjects compatibility of the vest with simulated Iltis driving task as being "'Reasonably Acceptable". There was no correlation between those that rated the vest as unacceptable for the simulated Iltis driving task and vest size.

4.5.5 Compatibility with the C7A1 Rifle During for the Standing Position

Although a large number of subjects (65) commented on problems during the standing C7A1rifle task only 12 subjects rated the compatibility of the vest with the standing C7A1 rifle posture as being unacceptable. Twenty-six subjects reported neck discomfort adopting the standing unsupported fire position and further 19 subjects commented that they experienced problems shouldering the rifle properly. Additionally, 19 subjects reported rifle butt slippage (see Figure 18) and lastly three subjects commented that the vest caused pressure point discomfort at the arm-hole when adopting the standing unsupported fire position. Overall the subjects compatibility of the vest with the standing unsupported C7A1 fire position as being "'Barely to Reasonably Acceptable". There was no correlation between those that rated the vest as unacceptable for compatibility with the standing C7A1 rifle position and vest size.

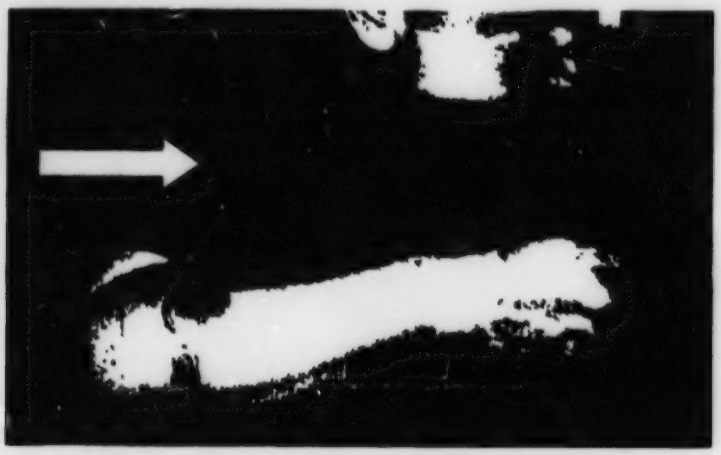


Figure 18: Rifle Butt Slippage

4.5.6 Compatibility with the C7A1 Rifle During for the Prone Position

Approximately 46% of the subjects commented on problem areas during the prone C7A1rifle task. Only nine subjects rated the compatibility of the vest with the prone C7A1 rifle posture as being unacceptable. Fifty-six subjects reported that the rest rode-up uncomfortably while adopting the prone unsupported fire position and further 22 subjects commented that they experienced problems at the neck area – see Figure 19. Finally 11 subjects commented that they had problems shouldering

their rifle with the vest when adopting the prone unsupported fire position. Overall the subjects compatibility of the vest with the prone unsupported C7A1 fire position as being "'Barely to Reasonably Acceptable". There was no correlation between those that rated the vest as unacceptable for compatibility with the prone C7A1 rifle position and vest size.

Figure 19: Problem Areas with the Prone Fire Position

4.6 Ballistic Plate Fit Acceptance

After completing the initial and dynamic fit acceptance, subjects were asked to assess the fit of the vest while wearing a set of ballistic plate inserts. Overall, the subjects rated the dynamic fit acceptance of the vests as being 'Reasonably Acceptable" – see Figure 20 and Table 8. Only three subjects rated their fit with plates as being unacceptable. Of these three subjects two had rated their fit with the vest alone as unacceptable while the third had rated their fit with the vest as being "Borderline". All three subjects were using the SS vest size and all found the vest too large for acceptable wear. There was no correlation between overall vest with plate fit acceptance versus fragmentation vest size.

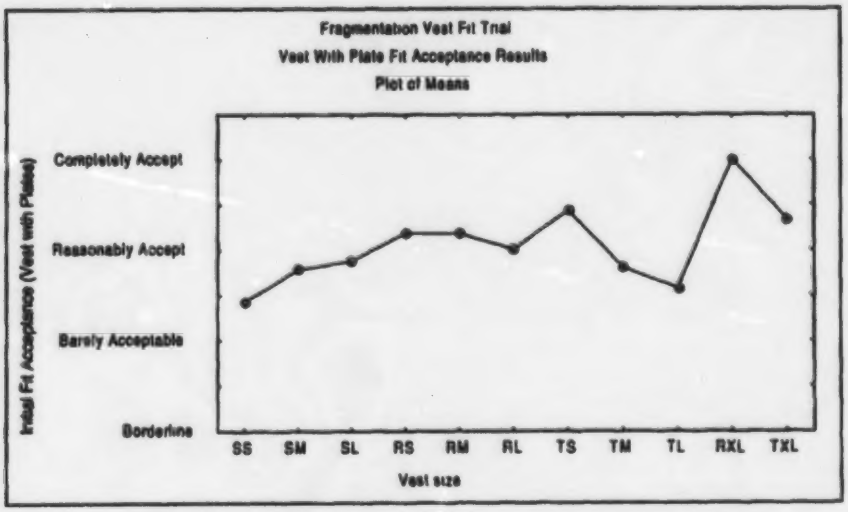


Figure 20: Vest with Plate - Overall Fit Acceptance Rating

While 87% of the subjects rated the fit as being acceptable, 8% of them rated the vest as being slightly small and 5% of them rated the vest as being slightly large.

Vest Size	Mean	SD	Total (n)
SS	5.4	1.3	31
SM	5.8	0.8	9
SL	5.9	0.4	8
RS	6.2	0.7	28
RM	6.2	0.6	51
RL	6.0	0.8	29
TS	6.4	0.6	14
TM	5.8	0.4	10
TL	5.6	1.3	7
RXL	7.0	0.0	1
TXL	6.3	1.2	3
Total	6.0	0.9	191

Table 8: Initial Vest with Plate Fit Acceptance Ratings

4.6.1 Plate Placement

The coverage provided by the front ballistic plate was examined Dvis- -vis the mid-sternal notch. Previous studies had identified the need to provide improved ballistic protection at the aortic arch, which is situated approximately 2.5 cm below the mid-sternal notch (suprasternale) – see Figure 21. Although plates were fully inserted into the plate carriers, the carrier was sewn too low to provide optimal coverage.

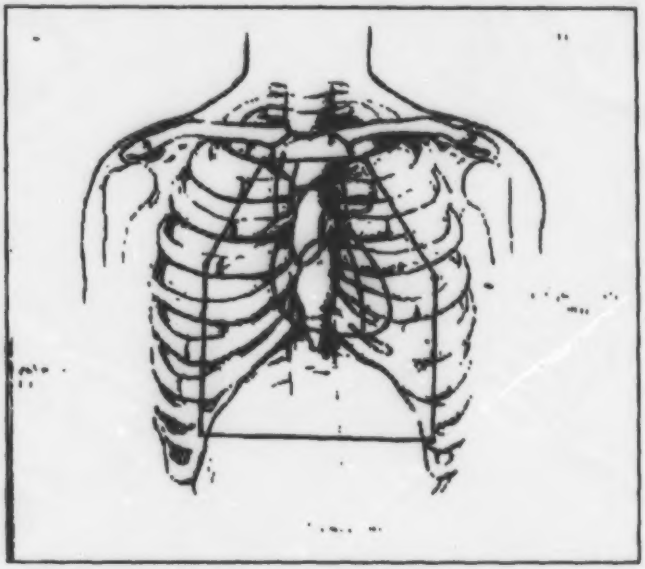


Figure 21: Plate coverage Versus Aorta

4.6.2 Plate Pressure Points

A total of 39 subjects (20%) reported pressure point discomfort when wearing the vest with the plates. Discomfort was noted where the edges of the plates contacted the areas of the shoulders (n=13), chest region (n=7), lower back region (n=7) see Figure 22, stomach region (n=4), the arm opening (n=4) and finally to pockets where the plate crushed their contents. One subject also commented that they had a pressure point at the front of the neck caused by the vest proper.

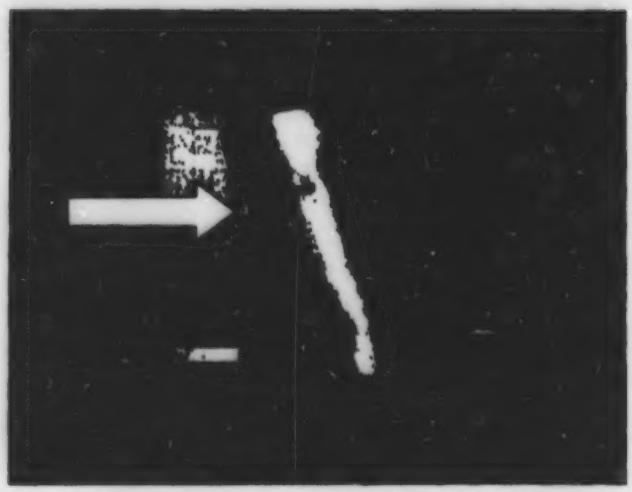


Figure 22: Pressure Point Areas with the Plate

4.6.3 Plate Chaffing

A total of 53 subjects (27%) reported chaffing when wearing the vest with the plates. Discomfort was isolated to the areas of the underarm (n=23) and neck region (n=30). There was no correlation between reported chaffing discomfort versus fragmentation vest size.

4.6.4 Plate Restrictions in Movement

A total of 48 subjects (25%) reported restrictions in movement when wearing the vest with the plates. Restrictions caused by the use of plates was most pronounced for arm movement, especially to the front and overhead (n=30). Plates also restricted bending (n=15) and neck rotation (n=3). There was no correlation between reported restrictions in movement versus fragmentation vest size.

4.6.5 Plate Interference

A total of 28 subjects (14.6%) reported clash between the C7A1 rifle and the ballistic plate – see Figure 23 and Table 9. Subjects wearing the larger chest sizes typically had greater clash than those with smaller chest sizes did.

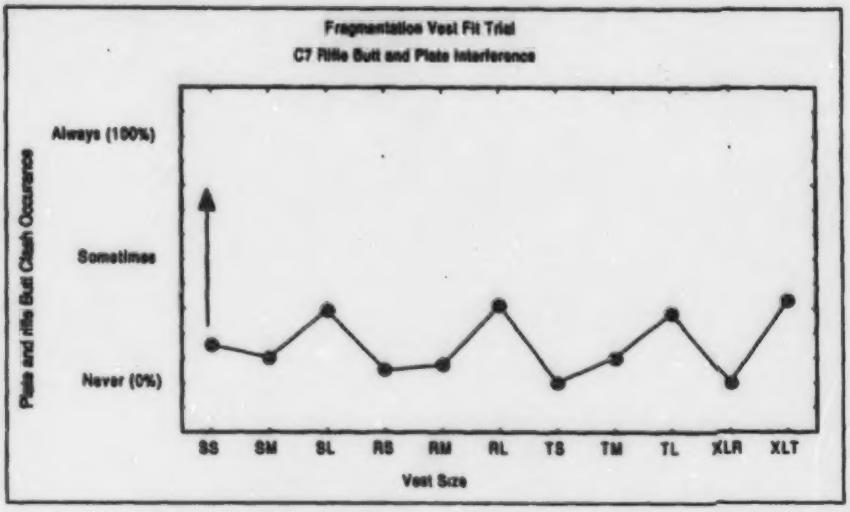


Figure 23: Plate Clash versus Vest Size

Restrictions caused by the use of plates was most pronounced for arm movement, especially to the front and overhead (n=30). Plates also restricted bending (n=15) and neck rotation (n=3). There was no correlation between reported restrictions in movement versus fragmentation vest size.

	Rifle Butt and Plate Clash		
Vest Size	Total (n)	Clash (n)	% Total
SS	31	4	12.9
SM	9	1	11.1
SL	8	2	25
RS	28	1	3.5
RM	51	8	16.3
RL	29	8	27.6
TS	14	0	0
TM	10	1	10
TL	7	1	14.3
RXL	1	1	100
TXL	3	1	33.3
Total	191	28	14.6

Table 9: Plate Clash versus Vest Size

In an attempt to identify key anthropometric factors for plate clash a post-hoc analysis of plate clash versus key chest dimensions was performed. While there was no significant correlation between plate clash and chest circumference or chest breadth, the analysis of plate clash and chest depth identified a significant ($p<0.0099$) relationship. Thicker chest depths resulted in more clashes. The traces of the rifle and plate clash regions were consolidated and are illustrated at Figure 24. The zone of the rifle and plate clash was approximately 2.5 cm wide.

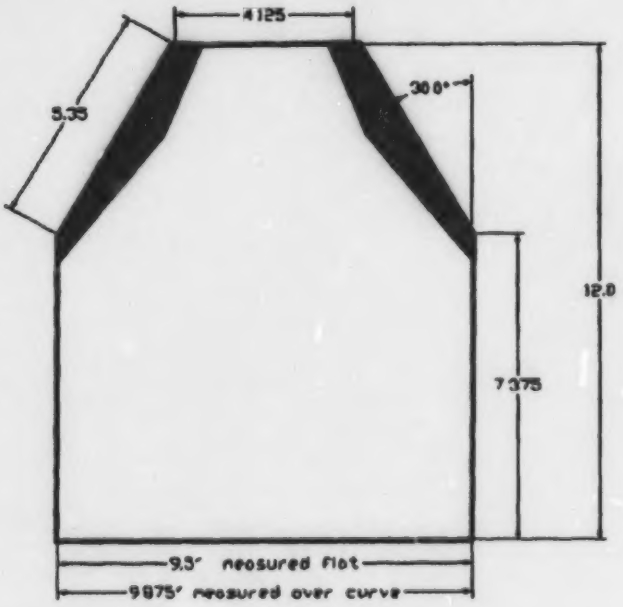


Figure 24: Regions of Rifle and Plate Clash

4.7 Ballistic Vest Coverage Assessment

4.7.1 Torso Coverage

During the initial assignment of vest sizes, torso size was based on coverage to the iliocristale landmark. Subjects with long torsos were assigned a "Tall " torso size, conversely subjects with a short torso size were assigned a 'Short" vest size. While stature was closely related to torso size, several subjects had proportionally shorter leg lengths or proportionally longer leg lengths. Mean ratings and standard deviations for the coverage provided by the vest sizes are indicated in Table 10 and demonstrated at Figure 25. On average the vest covered 7.6cm below the Iliocristale landmark.

Vest Size	Iliocristle Ht		Vest Hem Ht		Ht Difference (assessed individually)		Total (n)
	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD	
SS	101.3	18.6	93.2	4.6	8.1	18.0	31
SM	103.4	6.9	96.9	6.0	6.5	2.4	9
SL	102.3	4.6	94.0	5.0	8.2	2.7	8
RS	105.2	4.4	99.5	4.2	5.7	3.5	28
RM	106.2	3.9	98.6	3.4	7.5	2.6	52
RL	108.3	3.2	98.6	3.6	9.8	1.9	29
TS	113.8	3.6	107.5	3.1	6.3	1.2	14
TM	111.7	6.6	104.9	4.1	6.8	3.2	10
TL	110.0	7.1	103.7	1.8	6.4	7.4	7
RXL	100.4	0	91.4	0	9.0	0	1
TXL	117.9	8.1	107.4	4.7	10.6	2.3	3
All Groups	105.9	6.6	98.8	5.6	7.6	7.7	192

Table 10: Torso Vest Coverage (Hem Ht versus Iliocristale Ht)

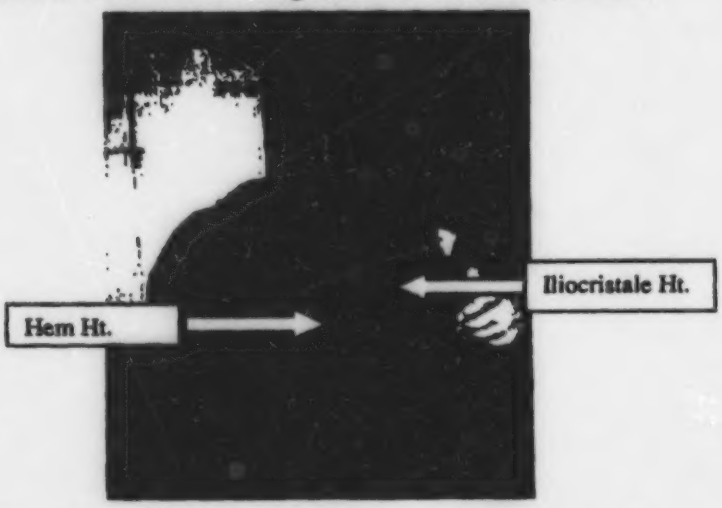


Figure 25: Torso Vest Coverage (Hem Ht versus Iliocristale Ht)

4.7.2 Neck Coverage

The fragmentation vest provided significant coverage to the subjects. The front ballistic panel covered up to approximately one centimeter below the suprasternale landmark (mid-sternal notch). Note the height reported below is for the height of the ballistic panel, not the vest shell material. The added vest shell covering material raised the apparent height of the vest to the suprasternale landmark. Mean ratings and standard deviations for the coverage provided by the vest sizes are indicated in Table 11. On average the vest covered up to 1.2cm below the Suprasternale landmark.

Vest Size	Suprasternale Ht		Vest Lower Neck Ht		Difference (assessed individually)		Total (n)
	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD	
SS	132.5	4.8	131.1	6.1	1.4	4.9	31
SM	138.7	6.8	137.4	6.2	1.2	1.0	9
SL	138.2	5.7	136.9	4.8	1.2	2.2	8
RS	141.1	3.8	140.5	4.3	0.6	2.0	28
RM	142.3	3.8	141.4	3.9	1.1	1.5	52
RL	144.6	3.2	143.2	3.9	1.4	2.0	29
TS	151.5	3.2	150.6	3.3	0.9	1.6	14
TM	150.0	3.8	150.6	4.3	-0.6	1.2	10
TL	151.5	2.2	147.7	9.0	3.8	9.3	7
RXL	141.2	0	137.4	0	3.8	0	0
TXL	158.8	6.5	156.1	7.1	2.7	0.8	3
All Groups	142.2	7.1	141.1	7.5	1.2	3.0	192

Table 11: Torso Vest Coverage (Neck Ht versus Suprasternale Ht)

4.7.3 Side Coverage

During the initial assignment of vest sizes, torso size was based on coverage to the iliocristale landmark and side overlap. Subjects with large torso circumferences were assigned a "Large " torso size, conversely subjects with a small torso circumference were assigned a 'Small" vest size. The amount of side overlap was measured while subjects were wearing combat clothing. Mean ratings and standard deviations for the side overlap coverage provided by the vest sizes are indicated in Table 12. On average the vest provided an average of 9.2 cm of overlap.

Vest Size	Individual Side Overlap		Total (n)
	Mean (cm)	SD	
SS	10.7	3.1	31
SM	9.4	1.6	9
SL	9.4	1.7	8
RS	8.6	1.4	28
RM	8.8	2.2	52
RL	9.3	2.0	29
TS	8.1	1.6	14
TM	9.3	2.1	10
TL	9.1	2.6	7
RXL	7.6	0	0
TXL	12.3	2.6	3
All Groups	9.2	2.3	192

Table 12: Side Overlap Coverage

Industry standards for ballistic protective vests providing total side coverage typically require up to 5 cm in side overlap. The results from the fitting trial indicate that there was on average 9.2cm in vest overlap. It should be noted that this overlap was measured with subjects wearing summer combat clothing only, the amount of overlap when wearing winter clothing would be reduced due to the bulk of the IECS jacket and parka. Using the results of Reference H, the average increase in male chest circumference over from summer to winter clothing (in-service and IECS) is approximately 46mm. As well, the average increase in male waist circumference when wearing arctic clothing (in-service and IECS) is approximately 40mm. Thus it can be expected that subject torso circumferences increase by approximately 4cm or 2 cm on each side. Thus in order to maintain the required safety overlap (5 cm on each side), an overlap of approximately 7cm is required to accommodate winter clothing (with subjects wearing combat clothing). These results suggest that the vest still provides excess coverage at the sides (approximately 2.2cm) for the hypothetical sizing system.

4.8 Final Fit Acceptance

Overall, the participants achieved an acceptable fit with the 11 vest sizes evaluated for both the plate and no-plate condition. On average, the subjects rated vest fit with and without plates as being "Reasonably Acceptable". The subjects assigned the Tall-Small (TS) vests rated the final fit of their size as being significantly more acceptable than those personnel assigned the Short-Small (SS) vest.

The number of subjects wearing the extra-large vests were too few in number for statistical comparison. Mean ratings for the fit of the vest sizes are indicated in Figure 26. Statistically significant differences ($p < 0.05$) are indicated.

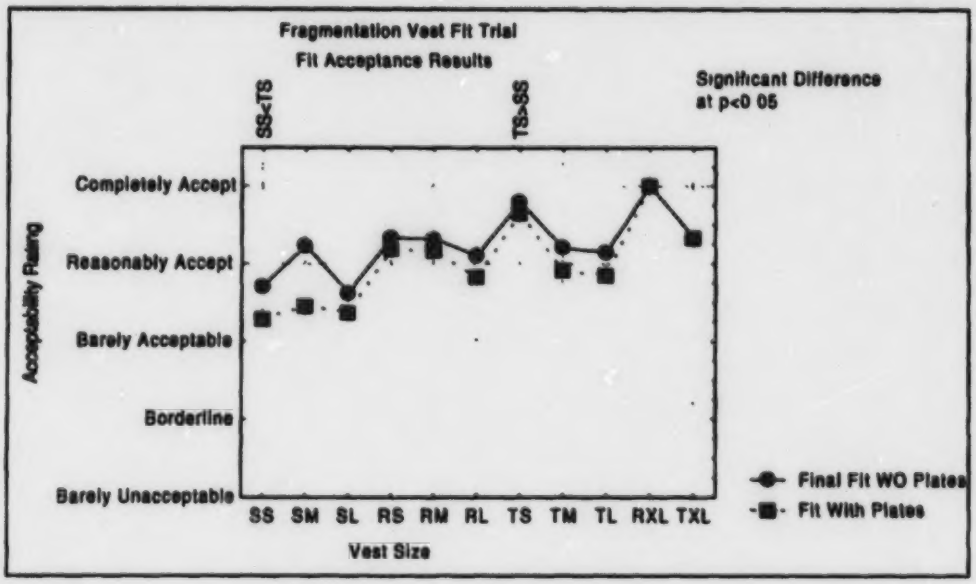


Figure 26: Final Fit Acceptance

4.8.1 Feature Fit Achievement

As part of the fit and adjustability questionnaire, participants rated the fit acceptance various vest features. Except for neck opening, the vest features were rated as being "Reasonably Acceptable". The acceptability of the neck opening varied from being "Borderline" to "Barely to Reasonably Acceptable". Although the vests contain approximately 4 cm of excess overlap for each size band, subjects did not rate the vest for chest circumference and waist girth as being unacceptable. This may be attributed to the fact that during the vest features briefing; subjects were informed of the need for side panel overlap to insure continuous coverage when adopting kneeling fire positions, etc. Thus subjects were cognoscente of the fact that they had overlap but not that the amount of overlap was excessive. The results of the feature fit acceptance for the various torso lengths are detailed below in Figures 27 to 29.

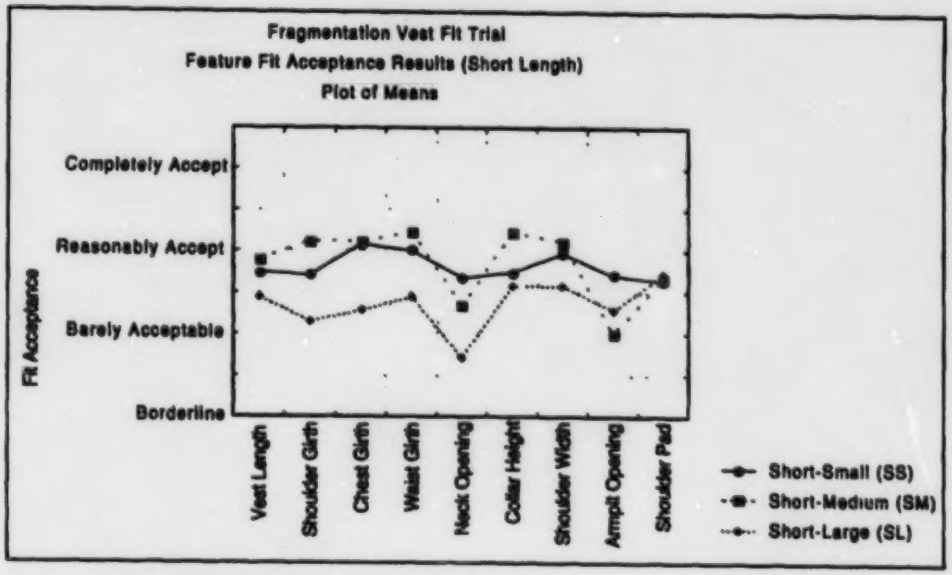


Figure 27: Feature Fit Acceptance for Short Length Vests

Except for the neck opening and armhole opening, the subjects (n=48) assigned to the Short length vest (SS, SM and SL) rated the vest dimensions "Reasonably Acceptable". Over 30% of these subjects rated the neck opening as being unacceptably small and 25% of these subjects rated the armhole opening as being unacceptably small.

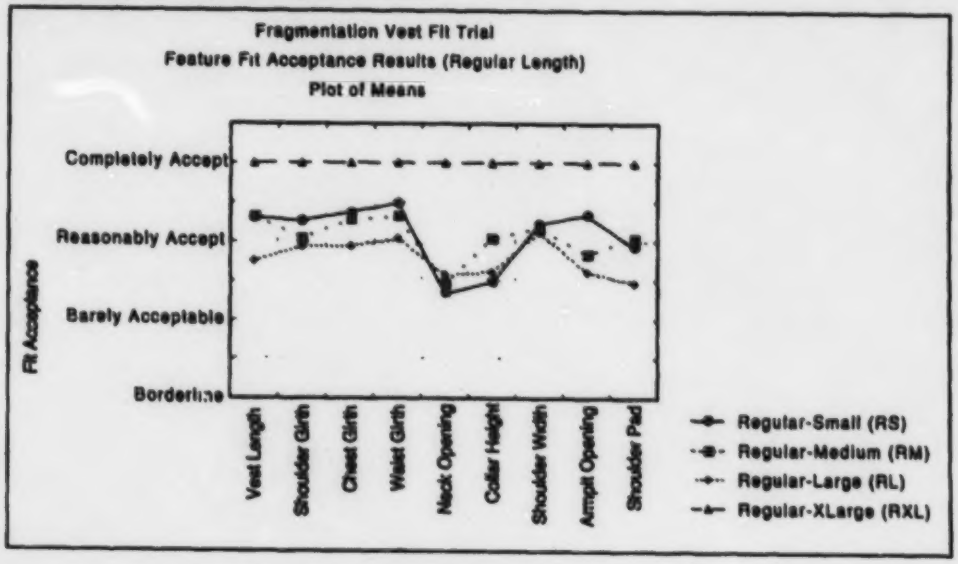


Figure 28: Feature Fit Acceptance for Regular Length Vests

Except for the neck opening, collar height and shoulder pad length, the subjects (n=110) assigned to the Regular length vest (RS, RM, RL and RXL) rated the vest dimensions "Reasonably Acceptable". Over 25% of these subjects rated the neck opening as being unacceptably too small.

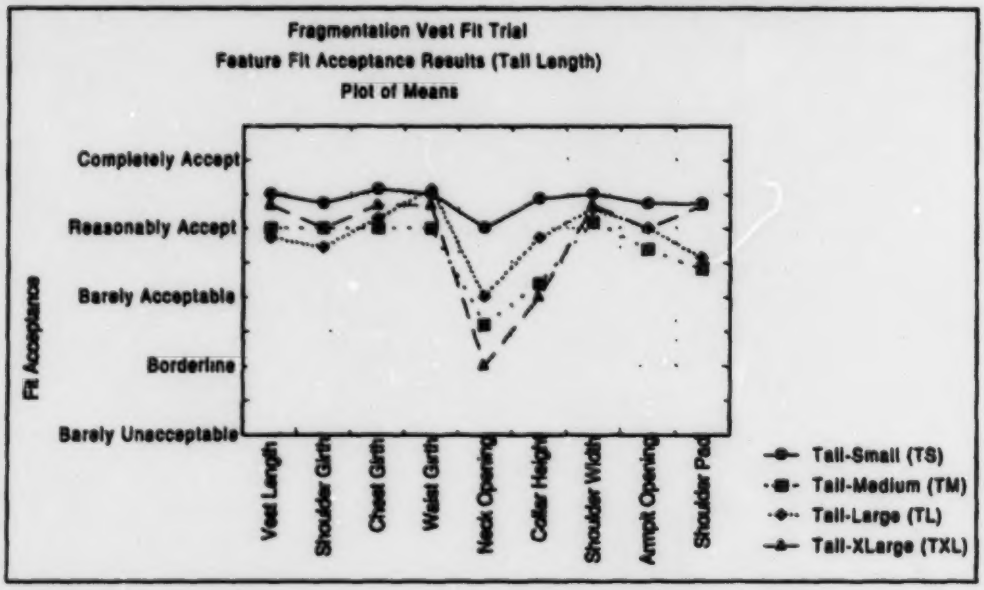


Figure 29: Feature Fit Acceptance for Tall Length Vests

Except for the neck opening, and collar height, the subjects (n=34) assigned to the Tall length vest (TS, TM, TL and TXL) rated the vest dimensions "Reasonably Acceptable". Over 35% of these subjects rated the neck opening as being unacceptably too small and over 20% of these subjects commented that the armpit opening was also unacceptably too small.

4.9 Limits of the Sizing System

Vest size assignment and body dimensions were analyzed to identify robust predictors of vest assignment. Considerable effort was expended in an attempt to identify a derived torso length measure, which would predict vest length assignment i.e. short, regular or tall. The rationale behind this approach was to use the same torso length or back length that will be used to assign the Clothe the Soldier (CTS) rucksack. Ultimately, the traditional and NATO standard measures of stature and chest circumference proved to be the best predictors of vest assignment.

4.9.1 Circumference Sizing Limits

Vest girth size assignment and body dimensions were analyzed to identify sizing limits. Chest circumference provided the highest correlation (R=0.81518) between vest circumferential selection and body dimension. A plot of vest assignment via chest size and stature is displayed below in Figure 30. Based on subject acceptance, chest size limits were established at 88, 98, 108, and 118 cm. –see Figure 31. While an extra-small chest size wasn't developed for this fit trial, a significant number of

smaller chest sized subjects rated the small vest as being too large. With a sizing limit of 98cm (38inches) for the Small vest size, over 70% of the females and approximately 30% of the males in the Land Forces would be accommodated in this one size.

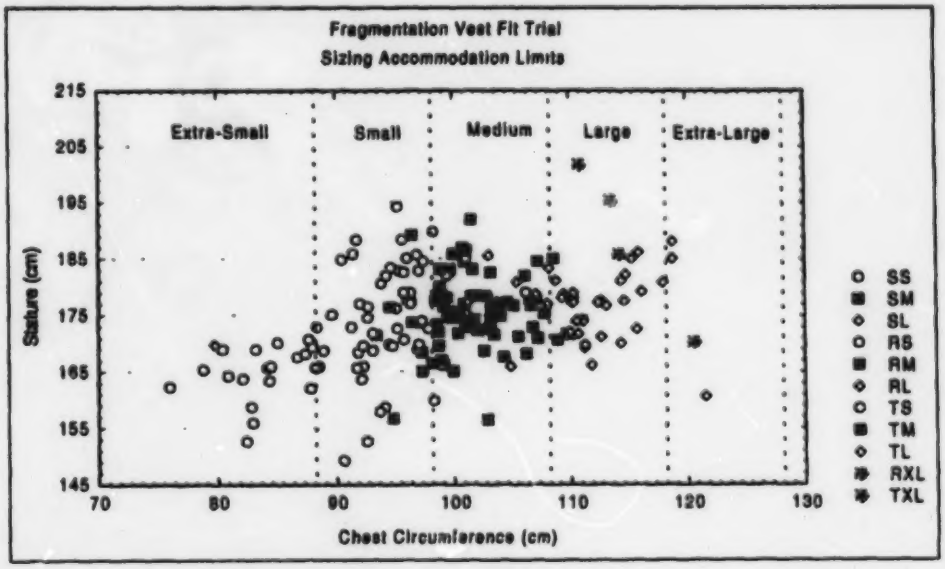


Figure 30: Chest Size Accommodation Limits

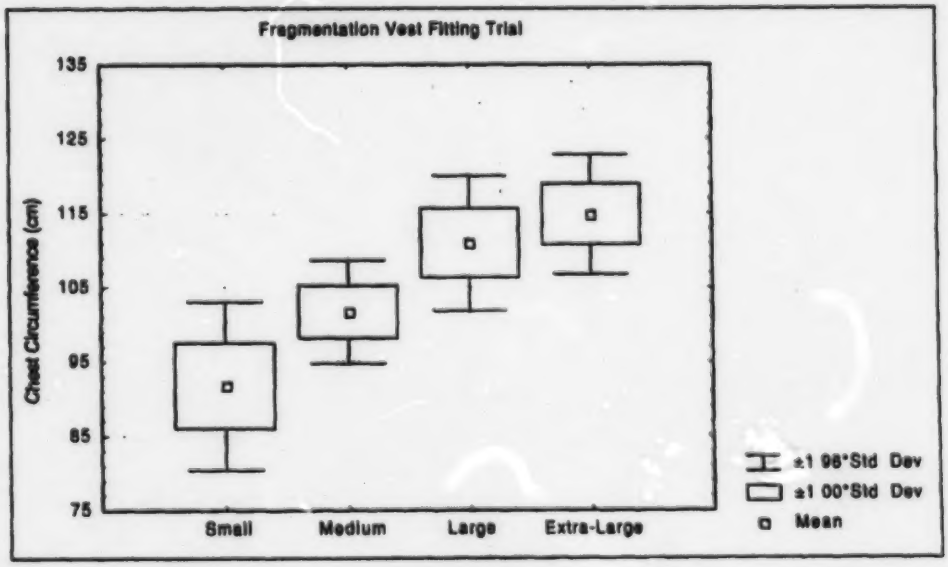


Figure 31: Scatterplot of Chest Circumferences Versus vest Sizes

As discussed in Section 4.7.3, even when taking winter clothing into consideration the existing vests contain approximately 4 cm of excess overlap for each size band (2.2 cm on each side). Thus in practice, the actual size accommodation limits were much larger – see Table 13. The Generation III vests fitted according to the next size up i.e. the small fit like a medium.

Chest Size	Hypothetical Chest Sizing (Inches) Limits	Actual Chest Sizing (Inches) Limits
Small	36-38	40
Medium	40-42	44
Large	44-46	48
X Large	48-50	52

Table 13: Chest Size Accommodation Limits (Note limits are in inches for compatibility with the NATO sizing system)

4.9.2 Stature Sizing Limits

Vest torso size assignment and body dimensions were analyzed to identify sizing limits. Suprasternale Height provided the highest correlation (R=0.78) between vest length selection and body dimension. Stature provided the next highest correlation (R=0.74) between vest length selection and body dimension. Back length and torso length (Suprasternale – Iliocristale Ht) did not provide strong correlations with selected vest length. In an effort to use traditional fitting measures, stature was chosen as the dimension for use in vest length sizing. A plot of vest assignment via chest size and stature is displayed below in Figure 32. While measuring stature is a fairly easy measurement to perform, it is not a perfect predictor of torso length. The Cormic index (proportion between the trunk and stature X 100) for the Land Forces (Reference G) varies between 49.94 to 59.78. Thus as with any population there is great variability in the shape of Land Forces personnel – see Figure 33.

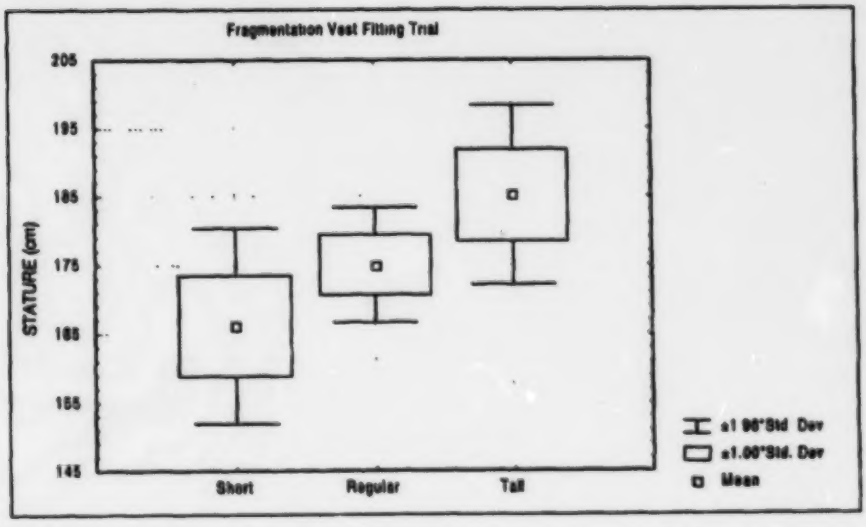


Figure 32: Plot of Stature Lengths versus Vest Size

Based on minimum coverage requirements and subject acceptance, stature size limits were established at 170 and 183 cm.

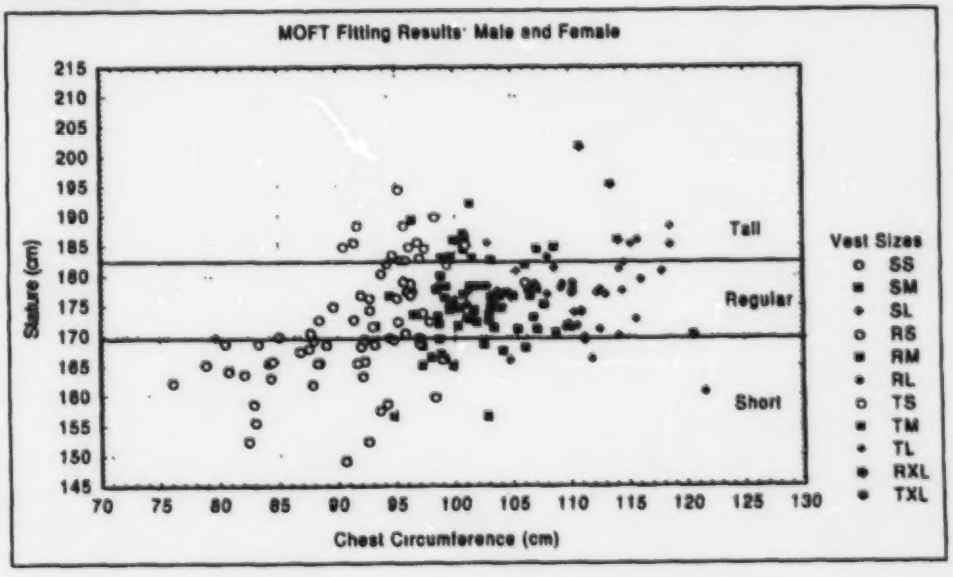


Figure 33: Stature Size Accommodation Limits

4.9.3 Validated Sizing System

The consolidated sizing system is as per Figure 34.

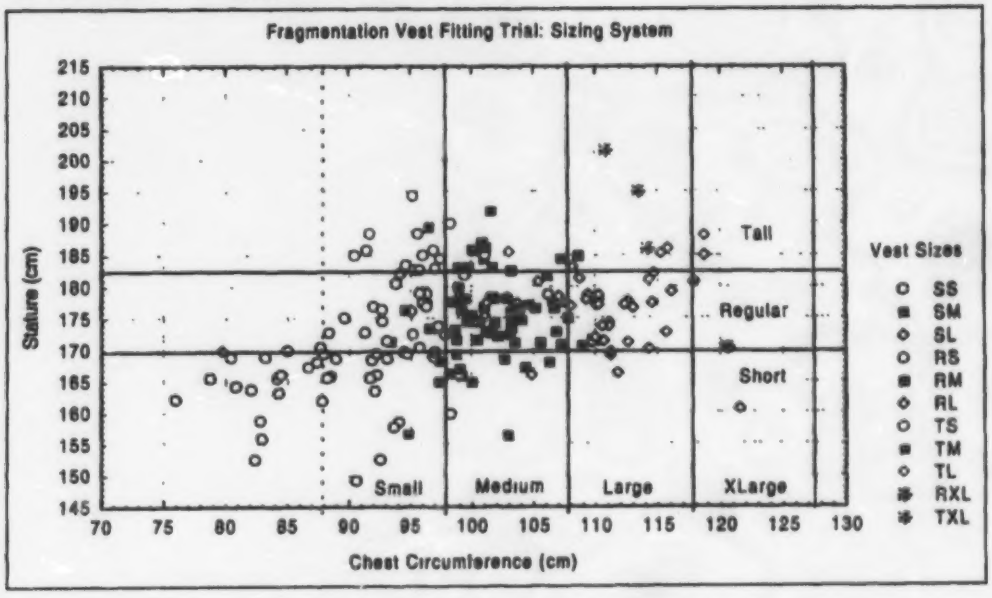


Figure 34: Consolidated sizing System

4.10 Land Forces Tariff

In order to determine a production tariff, the following information is required:

- Valid anthropometric data base
- Valid demographic data base
- Validated sizing system

The consolidated sizing system overlaid against the subjects in the anthropometric database is displayed in Figure 36. Due to the protective nature of the system being evaluated, a 98th percentile ellipsoid was used to visualize the required population coverage.

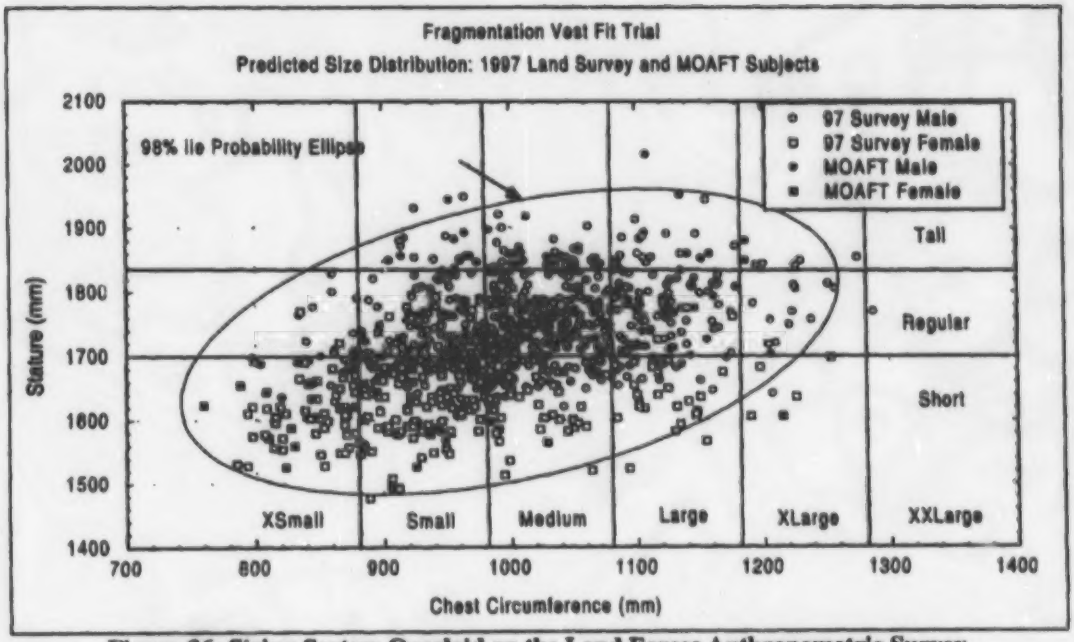


Figure 36: Sizing System Overlaid on the Land Forces Anthropometric Survey

4.10.1 Anthropometric Data Base

An anthropometric survey of the Land Forces was conducted in 1997-1998 (Reference G). A total of 465 men and 243 women of the Regular Force were measured. In all, 200 anthropometric measurements were obtained (140 direct, 56 derived, and 4 indices).

4.10.2 Demographic Profile

As of 31 December 1998 there were 53,410 established positions in the Land Forces, and of these 20,748 were Regular Force and 32,410 were Militia. As of 27 February 1999 there were 20,117 personnel in the Regular Force and of these 92.6% were male and 7.4% were female (Reference I).

4.10.3 Derived Regular Force Tariff

Once the limits of the sizing system were determined, the Land Forces Survey (Reference G) and demographic profile of the Land Forces (Reference I) was used to develop a Land Forces tariff. The Land Forces Survey database was sorted into predicted sizes and the relative frequency of males and females were used to set the tariff –see Table 14. The proposed tariff accommodates the identified need for a new extra-small size as well as an extra-extra-large size. Note this vest tariff does not accommodate the apparent excess overlap witnessed in all the chest sizes. This tariff also assumes that similar shaped Land Forces personnel will also utilize the same vest sizes as selected in the fitting trial.

Vest Tariff for Regular Force		
Chest Size	Height	Vest Size Tariff[1] Percentage
XSmall	Short	3.4
XSmall	Regular	1.6
XSmall	Tall	0
Small	Short	10.6
Small	Regular	14.9
Small	Tall	3.1
Medium	Short	7.9
Medium	Regular	28.1
Medium	Tall	6.8
Large	Short	3.2
Large	Regular	12.9
Large	Tall	3.9
X Large	Short	0.3
X Large	Regular	2.0
X Large	Tall	0.9
XXLarge	Regular	0.4
Total		100%

Table 14: Generation III Fragmentation Vest Tariff

NOTE 1: This assumes that males represent 92.6% of the Regular Land Force and females represent 7.4% of the Regular Land Force.

5. Discussion

The first aim of this trial is to conduct a fitting evaluation of modified Generation III Fragmentation Vest sizing system. The goals of a sizing system are to maximize the fit for vest style, protection, function and comfort. As well the goal is to minimize the number of sizes required. The Generation III Fragmentation Vest sizing system was based upon legacy systems within NATO, DND and industry. Thus this sizing system considered the following factors:

- Existing number of sizes already specified
- Possible range of adjustment
- Material type (elastic or non-elastic)
- Closeness of fit
- Design (cut), style, concept of fit, and materials.
- Tradition
- Protection limits.
- Sizes should be few in number and evenly distributed

The aim of this trial was not to develop a sizing system; rather it was to empirically test the limits of the theoretical sizing system. A review of the literature recommends that at least 10 subjects per size category are necessary to test the sizing system accuracy and garment fit acceptance. Except for the extra-large chest sizes, at least seven subjects or more were assigned to each size category. The male subjects in the fitting trial were predominantly combat arms soldiers (72.2%) and on average were taller and had smaller waists than those measured in the Land Forces survey.

While the sizing system predicted well for torso length, the hypothetical chest sizing limits were off by approximately 5 cm. While, the small vests were hypothetically sized for 36-38 inch chest circumference, they could actually accommodate personnel up to 40 inches in chest circumference (while wearing arctic clothing and while maintaining 5cm side overlap). All the vest chest sizes could safely accommodate larger chest circumferences than originally hypothesized; suggesting that the existing sizes could be re-labeled to reflect the next size up.

The over-sized nature of the chest sizes suggests the need for a normal small size or using the hypothetical sizing system – an extra-small size. Presently over 70% of the females and 30% of the males will be accommodated in the existing small chest size. Thus a significant number of females will be wearing a vest that is too large for them. Conversely, an examination of the Land Forces survey mapped against the sizing system suggests the need for an extra-extra large chest size (one subject has already been identified outside the largest vest size available).

A designer's and a subject's assessment of fit may be different. Except for a few subjects, nearly all the subjects chose a vest with excess side coverage. Thus on average, the subjects chose a larger fitting vest than necessary. Subjects may have preferentially selected the larger size to give them more comfort. Significant numbers of comments were received about vest stiffness (with the camouflage pattern shell) pressure points at the neck and pressure points at the arm opening, thus subjects may have taken the next size up to give them more room. The use of a more flexible shell material as well as minor changes to the vest design may reduce the frequency of subjects selecting the next size up. If these design changes are performed, then the vest tariff will change.

The use of ballistic plates did not affect normal vest fit acceptance. It had been hypothesized that a close fitting vest may not fit acceptably after the addition of plates. This was not witnessed during the trial, perhaps due to the fact that subjects preferentially selected larger fitting vests than necessary. The incidence of C7A1 rifle and ballistic plate clash was greatest for the larger chest depths. While rifle clash was witnessed, the affects of clash on performance were not determined.

6. Recommendations

Design Changes. The fragmentation vest fitting trial identified a number of vest design problem areas. These included excessive vest stiffness (with the camouflage shell), interference at the front of the neck, interference at the arm opening, excessive side overlap and a non-optimal front plate pocket position. The following vest design modifications are thus recommended:

- reduce vest shell stiffness
- modify the height of the vest collar (lower by 1.25 cm)
- raise the front plate internal pocket
- raise the vest panel hem (vest is too long).
- improve the arm-hole opening (lower by 1.25 cm)

Sizing System Changes. The requirement for a new extra-small size was identified during the fit trial. The current small chest size fits chest circumferences up to 40 inches, which is a medium size in industry. As well, the theoretical need for an extra-extra- large vest was identified during tariff calculations. Clothe the Soldier should investigate the actual need for developing these two new sizes.

Effects of Plate Interference. Although plate and C7A1 rifle clash was witnessed during the fit trial, the effects of plate clash on shooting performance is unknown. Clothe the Soldier should quantify the effects of plate interference prior to examining the need for plate redesign. Since plate clash was limited to approximately 2.5 cm at the side of the plate, casualty reduction models should be run to examine the effects of reducing the width of the plate.

Vest Tariff. A vest tariff was developed for the Generation III fragmentation vest. This tariff was based on this fitting trial that utilized relatively stiff vests (camouflage pattern shell). If vests are redesigned, as recommended above, then the vest tariff will have to be re- examined.

Annex A

to Generation III Fit Test Report:

Generation III Vest Features

Annex A
to Generation III Fit Test Report:
Generation III Vest Features

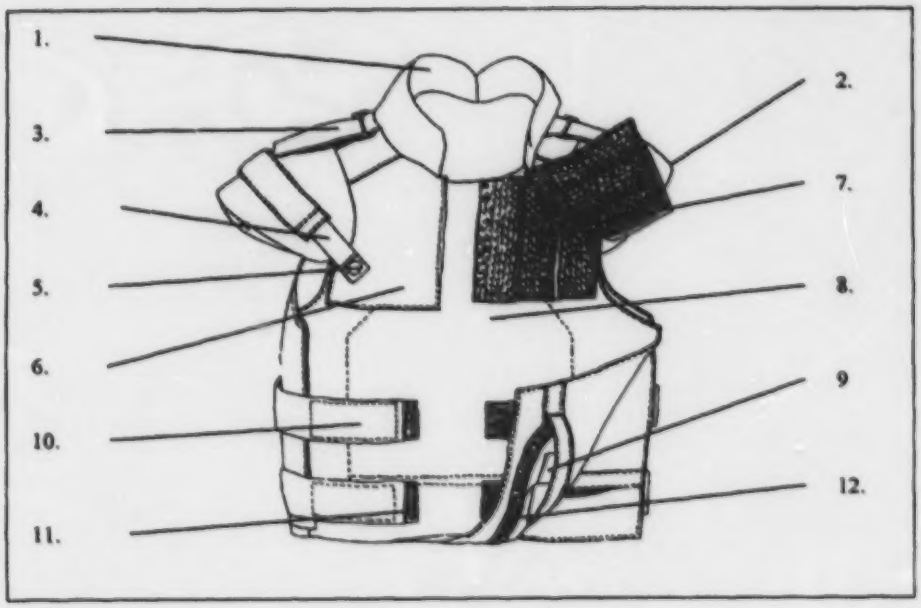


Figure 1: Vest A (Front View)

VEST A FEATURES	
1. Collar	2. Shoulder Pad
3. Shoulder Pad Strap	4. Shoulder Pad Elastic
5. Shoulder Pad Snap	6. Shoulder Adjustment
7. Shoulder Adjustment Velcro	8. Front Plate Pocket
9. Front Plate Pocket Velcro	10. Side Adjustment
11. Side Adjustment Velcro	12. Panel Pocket Velcro

Annex A
to Generation III Fit Test Report:
Generation III Vest Features

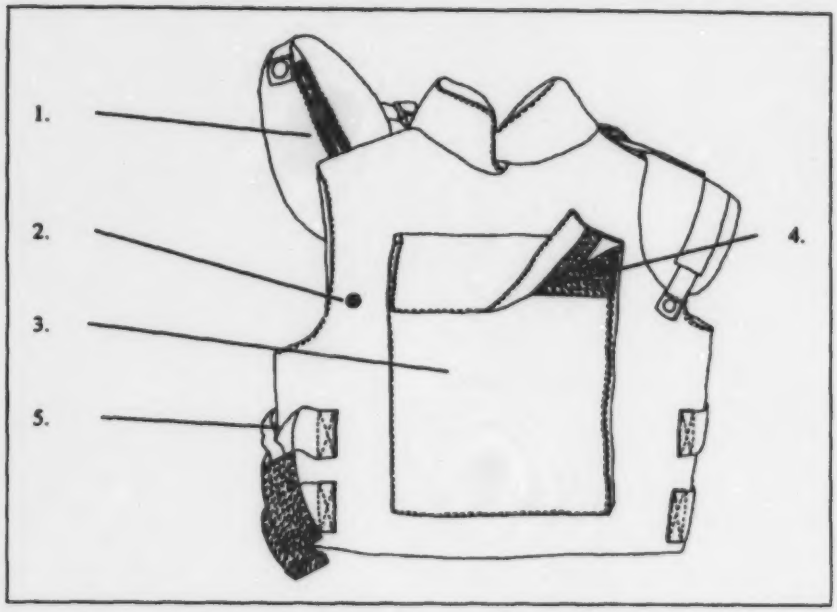
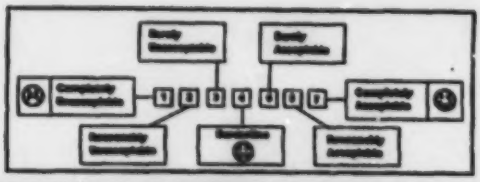


Figure 2: Vest A (Back View)

FEATURES
1. Shoulder Pad Panel Pocket Velcro
2. Shoulder Pad Snap (Back)
3. Rear Plate Pocket
4. Rear Plate Pocket Velcro
5. Side Elastic Limiter Strap
6. Side Strap Pull Tab (Not Shown)

Annex B
to Generation III Fit Test Report:
Initial Fit Acceptance Questionnaire

INITIALFIT2



PERSONAL DATA Clearly indicate your Name, Subject Number and Fragmentation Vest Size.

NAME

SUBJECT NUMBER

FRAG VEST SIZE

Rate the following Features	Fit Acceptance Rating 1 2 3 4 5 6 7	Fit Sizing: Short Small Tight				Long Large Loose
Initial Fit Impression	☐ ☐ ☐ ☐ ☐ ☐ ☐	☐	☐	☐	☐	☐

Comments

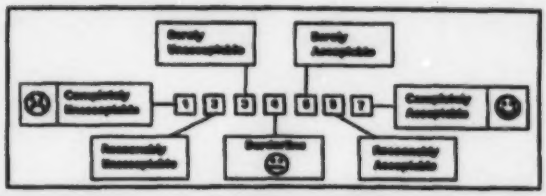
Rate the vest for the following comfort criteria	Comfort Rating 1 2 3 4 5 6 7	Comments
Pressure Points	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Chaffing	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Restrictions	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Overall Comfort	☐ ☐ ☐ ☐ ☐ ☐ ☐	

Annex C

to Generation III Fit Test Report:

Dynamic Fit Acceptance Questionnaire

FUNCTIONAL TEST 21



PERSONAL DATA Clearly indicate your Name, Subject Number and Fragmentation Vest Size

NAME

SUBJECT NUMBER **FRAG VEST SIZE**

Please note any decrements in ability to perform necessary functions or tasks, interferences with mobility, stress lines in the vests, bunching of the vest at the shoulders, waist, armholes, gaps in coverage, etc. (Use a camera to record problem areas.)

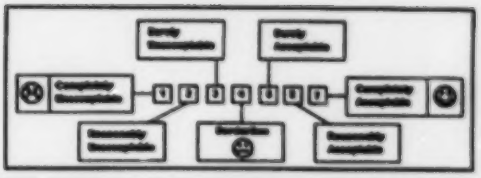
Please rate the functional ability to perform the following activities	Performance Rating 1 2 3 4 5 6 7	Comments
Waist bending, twisting (flexion)	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Arm movement (Shoulder abduction and flexion)	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Neck movement (extension)	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Iltis driving	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Rifle firing standing	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Rifle firing prone	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Overall ability to perform tasks	☐ ☐ ☐ ☐ ☐ ☐ ☐	

Annex D

to Generation III Fit Test Report:

Plate Fit Acceptance Questionnaire

PLATEFIT2



PERSONAL DATA	Clearly indicate your Name, Subject Number and Fragmentation Vest Size.
NAME	
SUBJECT NUMBER	FRAG VEST SIZE

Rate the following Features	Fit Acceptance Rating							Fit Sizing				
	1	2	3	4	5	6	7	Short Small Tight				Long Large Loose
Initial Impression - Fit With Plates	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

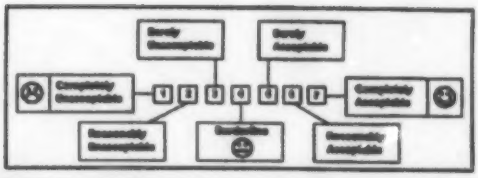
Comments

Rate the vest + . plates for the following comfort criteria	Comfort Rating							Comments
	1	2	3	4	5	6	7	
Pressure Points	☐	☐	☐	☐	☐	☐	☐	
Chaffing	☐	☐	☐	☐	☐	☐	☐	
Restrictions	☐	☐	☐	☐	☐	☐	☐	
Overall Comfort	☐	☐	☐	☐	☐	☐	☐	

Annex E

to Generation III Fit Test Report:

Final Fit Acceptance Questionnaire



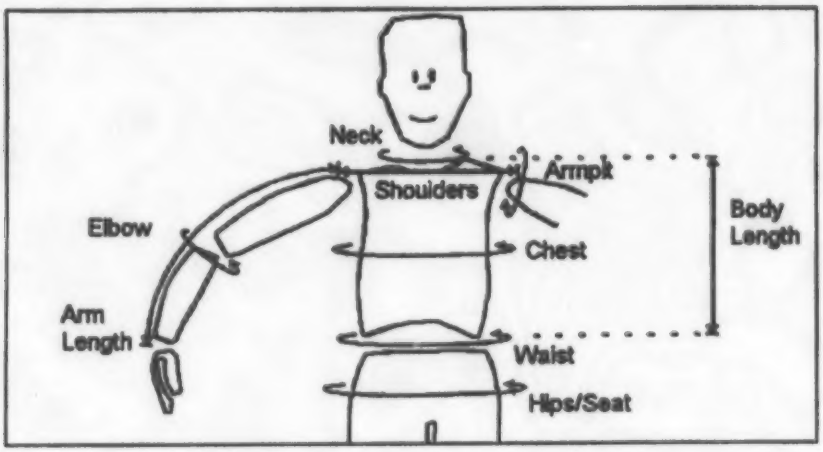
PERSONAL DATA **Clearly indicate your Name, Subject Number and Fragmentation Vest Size.**

NAME ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

SUBJECT NUMBER ☐☐ **FRAG VEST SIZE** ☐☐☐☐ **FRAG VEST Type**_____

Rate the following Features	Fit Acceptance Rating							Fit Sizing				
	☹ 1	2	3	😐 4	5	6	☺ 7	☹ Short Small Tight	😐	☺	😐	☹ Long Large Loose
Vest Length*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder Girth*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Chest Girth*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Waist Girth*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Neck Opening*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Collar Height	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder Width	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Armpit Opening*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder Pad	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fit with Front Plate	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fit with Rear Plate	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Final Fit No Plate	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Final Fit With Plate	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

* See Figure on Next Page



ADDITIONAL COMMENTS:

DOCUMENT CONTROL DATA SHEET

1a PERFORMING AGENCY	2. SECURITY CLASSIFICATION
Humansystems Incorporated, 111 Farquhar St, 2nd floor, Guelph ON, Canada, N1H 3N4	UNCLASSIFIED
1b PUBLISHING AGENCY	
DCIEM	

3 TITLE

(U) Fit Evaluation of Prototype Generation III Fragmentation Vest Designs

4. AUTHORS

Angel, Harold A

5. DATE OF PUBLICATION	6. NO OF PAGES
November 30 , 2000	64

7 DESCRIPTIVE NOTES

8 SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY

Sponsoring Agency: Director Land Requirements 5-10, National Defence Headquarters, 101 Colonel By Drive, Ottawa ON, Canada, K1A 0K2

Monitoring Agency:

Contracting Agency :

Tasking Agency:

9. ORIGINATORS DOCUMENT NO.	10 CONTRACT GRANT AND/OR PROJECT NO.	11 OTHER DOCUMENT NOS
Contract Report 2001-001	Contract No. W7711-7-7429/04-SRV	

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited

14 ABSTRACT

(U) 'In 1991, the Canadian Forces (CF) designed and built a fragmentation vest for the protection of our Land Forces personnel against ballistic threats during military operations. Operational deficiencies with the fragmentation vest were reported shortly after introduction into service; these deficiencies included: excessive stiffness, degraded mobility, and incompatibility with helmets, weapon sights and in-service personal load carriage equipment. In order to resolve the in-service vest deficiencies, a series of human factors (HF) investigations were undertaken to develop a new fragmentation vest design. Once a basic design was finalized it was recommended that a detailed fit test should be undertaken to determine tariff and fit boundaries. A hypothetical sizing system containing 11 sizes was developed based on industry standards and the in-service sizing system.

There were three aims to the Generation III Fragmentation Vest Fit Evaluation Trial trial. The first aim of this trial was to conduct a fitting evaluation of modified Generation III Fragmentation Vest sizing system. The second aim was to investigate the degree interference between the hard armour plates and C7A1 rifle firing tasks. The final aim of this trial was to use the results of the trial to propose a sizing and tariff system for the Land Forces.

A three day fit trial was conducted with 198 (168 males and 30 females) subjects at CFB Petawawa during the period 7 to 11 June 1999. Subjects were required to pass through a number of separate fit test stands and anthropometry stands, these stands included: initial fit assignment, dynamic fit acceptance, fit acceptance with ballistic plates, plate interference, ballistic coverage and final fit acceptance. Except for short-small size, the participants achieved an acceptable fit with the 11 vest sizes evaluated for both the plate and no-plate condition.

A requirement for a new extra-small size was identified during the fit trial, the current small chest size fits chest circumferences up to 101.6 cm, which is considered a medium size in industry. All the vest chest sizes could safely accommodate larger chest circumferences than originally hypothesized; suggesting that the existing sizes could be re-labeled to reflect the next size up.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Generation III Fragmentation Vest; Fragmentation Vest; Ballistic Vest; Ballistic Protection; Clothe the Soldier; Human Factors Evaluation; Fit trial; Generation II Fragmentation Vest; Field Trial; sizing tariff